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NICMOS IMAGING OF INFRARED-LUMINOUS GALAXIES

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ABSTRACT

We present near-infrared images obtained with the HST NICMOS camera for a sample of 9 luminous (LIGs: $L_{\rm IR}(8-1000\mu{\rm m}) \geq 10^{11}$ L$_\odot$) and 15 ultra-luminous (ULIGS: $L_{\rm IR} \geq 10^{12}$ L$_\odot$) infrared galaxies. The sample includes representative systems classified as warm ($f_{25\mu{\rm m}}/f_{60\mu{\rm m}} > 0.2$) and cold ($f_{25\mu{\rm m}}/f_{60\mu{\rm m}} \leq 0.2$) based on the mid-infrared colors and systems with nuclear emission lines classified as HII (i.e. starburst), QSO, Seyfert and LINER. The morphologies of the sample galaxies are diverse and provide further support for the idea that they are created by the collision or interactions of spiral galaxies. Although no new nuclei are seen in the NICMOS images, the NICMOS images do reveal new spiral structures, bridges, and circumnuclear star clusters. The colors and the luminosities of the observed clusters are consistent with them being young (10^{7-8} yrs), formed as a result of galactic interactions and having masses much greater than those of Galactic globular. In NGC 6090 and VV114, they are preferentially situated along the area of overlap of the two galactic disks.

With the exception of IR 17208-0018, all of the ULIGs have at least one compact (2.2μm FWHM $\leq$ 200 pc) nucleus. Analysis of the near-infrared colors (i.e., $m_{1.1-1.6}$ vs. $m_{1.6-2.2}$) derived from 1.1$''$ diameter apertures suggests that the warm galaxies have near-infrared colors consistent with QSO+hot dust emission and the cold galaxies, as a group, have near-infrared colors consistent with reddened starlight. In addition, the cold ULIG UGC 5101 (and possibly three others) have near-infrared colors suggesting an additional AGN-like near-infrared component in the nucleus. In a 2 kpc-diameter aperture measurement, the global colors of all of the cold galaxies except UGC 5101 are consistent with starlight with a few magnitudes of visual extinction. The general dichotomy of the near-infrared properties of the warm and the cold galaxies are further supported by the light distributions - seven of the eight warm galaxies have unresolved nuclear emission that contributes significantly (i.e., $\geq 30-40\%$) to the total near-infrared luminosity. The smooth, more extended light observed in all of the galaxies is most likely comprised of giant and supergiant stars, but evidence at longer wavelengths suggests that these stars contribute little to the high 8–1000μm luminosity of these galaxies. Finally, light profiles of nine of the 24 systems were fit well by an r$^{1/4}$ law (and not so well by an exponential disk profile). Whether these star systems eventually become massive central bulges or giant elliptical galaxies will depend on how efficiently the present ISM is converted into stars.

Subject headings: galaxies: active — galaxies: ISM — galaxies: ULIG — galaxies: interactions — galaxies: starburst

1. INTRODUCTION

Luminous infrared galaxies, which emit a substantial amount of their bolometric luminosities in the wavelength range 8–1000 μm (e.g. Rieke & Low 1972; Soifer et al. 1987; see Sanders & Mirabel 1996 for a review), are observed to be in a phase of dynamically triggered evolution. Ground-based optical to near-infrared imaging of the most powerful galaxies detected in the IRAS survey (Soifer et al. 1987) have revealed that virtually all show evidence of a strong interaction (eg. extended tidal tails) or double nuclei (cf. Joseph & Wright 1985; Armus, Heckman & Miley 1987; Sanders et al. 1988a; Clements et al. 1996; Murphy et al. 1996). Extensive optical and near infrared spectroscopic surveys have shown that these galaxies can be classified as luminous starbursts and active galactic nuclei, AGN (Sanders et al. 1988a; Armus, Heckman & Miley 1989; Kim et al. 1995, 1998; Veilleux, Kim & Sanders 1999; Veilleux, Sanders & Kim 1999), both of which are presumably fueled by the abundance of molecular gas (Sanders, Scoville & Soifer 1991; Solomon et al. 1997) that collect via gravitational torques and dissipate

into the merging nuclei (Mihos & Hernquist 1996; Scoville et al. 1997; Bryant & Scoville 1996). Most of the direct ultraviolet and optical light emitted by these starbursts and AGN is obscured by the interstellar dust of the merging galaxy, but is re-emitted at far-infrared wavelengths.

Evidence of morphological disturbances (e.g. Mackenty & Stockton 1984) and large amounts of molecular gas (e.g. Sanders, Scoville, & Soifer 1988) and dust in a few optically-selected QSOs, combined with the similarities in the space densities of QSOs and ULIGs (Soifer et al. 1987), initially led to the hypothesis that ULIGs might evolve into optically-selected QSOs, once most of their gas and dust are consumed/blown out by star formation and AGN activity (Sanders et al. 1988a, Sanders et al. 1988b). During this process an accompanying evolution in the far-infrared color, from cold, starburst-like colors to warm, Seyfert-like colors, takes place (Sanders et al. 1988b). The scenario is supported by optical and mid-infrared spectroscopy, which shows an increasing fraction of AGN-like emission-line spectra in ULIGs as a function of increasing luminosity (Veilleux, Kim & Sanders 1999; Veilleux, Sanders & Kim 1999; Evans et al. 1998; Lutz et al. 1998).

While the nature of the luminous infrared galaxies are believed to be understood in general terms, the details have been under investigation for over a decade. However, the wealth of ground-based spectroscopic and low resolution imaging surveys have provided little information on the circumnuclear region at scales comparable to the dimensions of the starbursts and/or AGN believed to be responsible for the bulk of their bolometric luminosities. Optical imaging of these galaxies has been obtained with Hubble Space Telescope (HST) with resolutions $< 0.1''$; however, at these wavelengths the circumnuclear regions are still obscured by the high dust column densities. The recent installation of the Near-Infrared Camera and Multi-Object Spectrometer (NICMOS) on HST has now made it possible to observe more directly the embedded nuclear regions by providing the high resolution possible with HST (0.1–0.2$''$, which corresponds to 30-200 pc over the redshift range 0.01–0.1) at wavelengths where the effects of dust extinction are reduced by an order of magnitude (in exponential optical depth) compared to visual wavelengths. We present here an investigation of the near-infrared morphologies of 24 luminous infrared galaxies using the new capabilities of HST. The analyses and conclusions drawn from this study benefit from previous ground-based imaging and spectroscopy of these galaxies.

This paper is divided into eight Sections. Section 1 concludes with a discussion of the general objectives of the survey and the sample selection. In §2, the observations, data reduction, and flux calibration are summarized. Included here is a description of the Point Spread Function (PSF) subtraction performed on the brighter, unresolved nuclei and the extinction corrections applied to the 2.2 μm images. The morphologies of the individual galaxies are summarized in §3 and §4, followed by a discussion of the aperture colors and their intepretation in §5. Section 6 contains a discussion of the radial profile fits to the images and how well they are fit by elliptical galaxy and exponential disk profiles. In §7, the degree of central compactness is discussed, and in §8 the nature of the extended near-infrared light is considered. Section 9 is a summary of the paper. Throughout this paper, we adopt H_0=75 km s^{-1}Mpc^{-1} and $q_0 = 0$; at the typical redshift (z=0.05) of the observed galaxies, 0.1–0.2$''$ resolution corresponds to 100–200 pc.

1.1. *General Objectives*

The NICMOS images are particularly well-suited to defining the small-scale structure of the dust embedded galactic nuclei in infrared luminous galaxies. The 1.1, 1.6, and 2.2 μm measurements can be used to determine the distribution of dust extinction (assuming intrinsic colors of the embedded stellar populations) and the observed light distribution corrected for this extinction to better estimate the 'true' light distribution. The issues we address here include :

1) the location and size of the galactic nucleus (or nuclei) – an unresolved resolved nucleus (i.e. $\leq 0.1''$) might indicate an AGN or compact, super-luminous starburst – and whether the fraction of the total 2.2 μm light emitted from compact nuclear sources is correlated with the total bolometric luminosity or the optical emission line spectral classification and far-infrared color.

2) the morphology of the dust extinction in the galactic nuclei as an indication of central dust accretion disks or rings

3) the existence of inner spirals or bars both of which could transport material to the nucleus and stimulate starbursts in the inner disk

4) the properties and distribution of luminous (presumably young) star clusters formed in the galactic disks and nuclear regions

5) the stellar surface brightness profiles and their relationship to the stage of dynamical evolution of the galaxies

1.2. *NICMOS Luminous Infrared Galaxy Sample*

The sample of galaxies range in infrared luminosities from 10^{11} to 4 x 10^{12} $L_\odot$ at λ=8-1000 μm. The sample is not complete in a flux or distance limited sense, but is instead intended to cover a broad range of luminosity and intrinsic properties (and presumably evolutionary stages). The majority of the galaxies were taken from the IRAS Bright Galaxy Survey which includes all extragalactic objects (324 galaxies) brighter than 5.4 Jy at 60 μm at $|b| \geq 30°$ and $\delta \geq -30°$ (Soifer et al. 1989). Since one of the primary objectives of this study was to look for morphological similarities between the ultraluminous infrared galaxies, AGNs and nuclear starbursts, we have included for reference two optically-selected QSOs which are also warm ultraluminous infrared galaxies (3C48 and Mrk 1014) and the relatively nearby starburst galaxy NGC 6090. We then selected a large fraction of the most luminous systems, the ultraluminous infrared galaxies (ULIGs) which have L$\geq 10^{12}$ $L_\odot$ at λ=8-1000 μm. Nine of the ten galaxies in the original list of ULIGs (Sanders et al. 1988a) are included here; the remaining object (Mrk 231) was imaged in a companion study by Hines et al. (1999). We also include here 5 of the 12 objects contained in the warm ultraluminous sample (Sanders et al. 1988b); these were not in the BGS due to their lower 60 μm flux. As stated in the Introduction, the warm ULIGs have been suggested as a transition class between the cold ULIGs and optical/UV excess QSOs.

The galaxies in this sample are listed in Table 1 along with their optical nuclear emission line and mid-infrared warm (W) versus cold (C) classifications (with the dividing line between the two classes at a 25-to-60 μm flux density ratio of 0.20: de Grijp et al. 1985; De Grijp Lub & Miley 1987; Low et al. 1988; Sanders et al. 1988b), their λ=8-1000 μm luminosities, molecular hydrogen masses (based on mm-CO emission; Sanders, Scoville & Soifer 1991) and a description of the morphology seen in the NICMOS images. Fig. 1 shows the sample galaxies plotted as a function of L_{ir} at λ=8-1000 μm and their 25-to-60 μm flux density ratios. The classification of the optical emission-line ratios are indicated by the different symbols.

2. OBSERVATIONS AND DATA REDUCTION

HST observations of each galaxy were obtained in a single orbit (except VV114) on the dates listed in Table 2 using camera 2 of NICMOS. The camera has a 256×256 HgCdTe array with pixel scales of 0.0762″ and 0.0755″ per pixel in x and y, respectively, providing a $\sim 19.5'' \times 19.3''$ field of view (Thompson et al. 1998). Images were obtained using the wide-band F110W (1.10 μm, $\Delta\lambda_{\rm FWHM} \sim$ 0.6 μm) and F160W (1.60 μm, $\Delta\lambda_{\rm FWHM} \sim 0.4$ μm) filters, and the medium-band F222M (2.22 μm, $\Delta\lambda_{\rm FWHM} \sim 0.14$ μm) filter. During five of the orbits, suitably placed HST guide stars were also imaged for point-spread function (PSF) determinations. The FWHM are 0.11″, 0.16″, and 0.22″ at 1.1, 1.6, and 2.22 μm, respectively. Observations of both the galaxies and the PSF stars were done using a four or five-point spiral dither in each filter setting; the step size in most cases was 25.5 pixels (1.91″). The dithered observing mode yields better sampling of the PSF (due to the half-pixel steps) and the ability to identify bad-pixels, pixels temporarily affected by cosmic rays, and processing artifacts. At each dither position, non-destructive reads (MULTIACCUM) were taken. The total integration times for each filter are listed in Table 2. Dark images were obtained at the end of each orbit.

The initial data reduction and calibration was done with IRAF. The dark was first created, then the NICMOS data were dark subtracted, flatfielded and corrected for cosmic rays using the IRAF pipeline reduction routine CALNICA (Bushouse 1997). The calibrated images contained pixels with reduced quantum efficiency due to contaminants on the array surface, thus a mask was created to minimized their effect. Two additional areas required masking; the coronographic hole was masked on all images, as well as column 128, which is noteably sensitive to minute discrepancies in dark subtraction (i.e., the dark current rises sharply toward the center column of the array). The dithered images were then shifted and averaged using the DRIZZLE routine in IRAF (e.g. Hook & Fruchter 1997). The plate scales of the final "drizzled" images are 0.0381″ and 0.0378″ per pixel in x and y.

The reduced images are shown as 3-color images in Fig. 2. Because of the very large dynamic range and signal-to-noise ratio in the surface brightness of the galaxies, a variable resolution smoothing routine (see Appendix A) was applied to the image data for the contour maps (Fig. 3 and 4). This routine smooths the image with a variable width boxcar filter with the resolution depending on the local signal-to-noise ratio across the image.

For each galaxy, the three broad-band images were obtained during a single guide star acquisition within one orbit. Since the stability of the guide star tracking for all of these NICMOS observations is much better than a single pixel, the relative registration of the three images was assured. On the other hand, in no instance did we attempt absolute registration of the images using multiple guide stars. We therefore adopt coordinates in each galaxy measured as offsets from the 2.2 μm peak, using the same pixel origin for the 1.1 and 1.6 μm images. All of the images are rotated with north up and east to the left using the data-header orientation angle.

2.1. *Flux Calibration*

Flux calibration of the images were done using scaling factors of 2.031×10^{-6}, 2.190×10^{-6}, and 5.487×10^{-6} Jy (ADU/sec)$^{-1}$ at 1.10, 1.60, and 2.2 μm (Rieke et al. 1999). The corresponding magnitude zero points (on the Vega system) were calculated assuming 1775, 1083 and 668 Jy at 0 mag for 1.10, 1.60, and 2.22 μm respectively. The effective wavelengths of the 110W, 160W and 222M filters on NIC2 are 1.104, 1.593, and 2.216 μm (Rieke et al. 1999).

As a check on the flux calibration, we compared our measured fluxes within a 5″ aperture centered on the 1.6μm and 2.22μm peaks in each galaxy with those measured in ground-based imaging by Carico et al. (1988). For the 16 galaxies which overlap between the two samples, the flux densities of all but one (IR 12112+0305) agree to better than 10%. At 1.1μm a direct comparison is not possible since the standard J filter is at 1.25μm. The rms noise in the final images is typically 7, 7 and 20 μJy (arcsec)$^{-2}$ at 1.1, 1.6, and 2.2 μm.

2.2. *Point Source Subtraction and Image Artifacts*

In seven of the galaxies imaged here, the images are contaminated by diffraction rings and spikes due to strong point sources in the galactic nuclei. These effects are severe in NICMOS images due to near-field diffraction from the cold-stop. The effects are particularly noticeable at 2.2 μm but are also seen in some of the 1.6 and 1.1 μm images. For the affected images, the nuclear point sources were subtracted with PSF stars. Given the variability of the HST PSF caused by telescope breathing, this removal of the PSF is only approximate. To avoid spurious PSF artifacts being interpreted as real structure in the images, we therefore set the surface brightness within a box centered on the point source to a constant value equal to the average of the flux along the outside border of the box. This square box had dimensions of 0.66, 0.96 and 1.32″ on a side at 1.1, 1.6 and 2.2 μm respectively. A point source with the fitted flux was then convolved with a Gaussian of FWHM = 0.11, 0.16 and 0.22″ and added back into the PSF-subtracted image at the position of the point source in the galaxy. This procedure was only adopted in the contour diagrams in order to retain information on the point source strength while at the same time avoiding the display of areas of the image believed to be particularly unreliable. The procedure was applied to Figs. 3 and 4 for NGC 7469, IRAS 08572+3915, IRAS 05189-2524, PKS

[1]Note that no flux measurements were made from images processed in this manner.

1345+12, IRAS 07598+6508, Mrk 1014 and 3C48. [1] None of the 3-color images displayed in Figure 2 have any PSF subtraction.

Due to the higher resolutions in the two shorter wavelength bands and our desire to show the original, unconvolved (but calibrated) data for the 3-color images, these images occasionally exhibit 'color fringes' in areas with steep brightness gradients (eg. near a bright point source). The alternatives (convolving all wavelengths to a common 2.2 μm resolution or deconvolving to the 1.1 μm resolution) would have degraded the short wavelength resolution or been susceptible to artifacts of the deconvolution technique. Therefore, the color-fringes appearing in areas with steep intensity gradients in the 3-color displays should be viewed with caution and in most cases ignored.

2.3. *Extinction Derivation and Correction*

In most of the galaxies, large spatial variations in the colors of the near-infrared emission are seen across the images. Aside from the nuclear point sources (which may have different intrinsic colors), most of the large-scale color gradients are probably attributable to variations in the dust extinction within the galaxy. This implicitly assumes that outside the nucleus there is little contribution to the flux from warm dust and that the galactic disk stellar light in the near infrared is mostly that of a $\sim 10^8$ yrs stellar population rather than that of the old disk population (age $\geq 10^9$ yrs). We thus correct the 2.2 μm images for extinction under the assumption that the intrinsic spectrum of the extended emission is that of an aging starburst population with the extinction derived from the observed $m_{1.6-2.2}$ μm color. For the intrinsic colors, we use the Bruzual & Charlot (1993, 95) model starburst population having a Salpeter IMF (see below) over the mass range 0.1-125 $M_\odot$. For an instantaneous starburst with solar metallicity, we sample the stellar light in the NICMOS filter set as a function of time. At ages 5×10^7–5×10^8 yrs, the 1.1, 1.6 and 2.2 μm colors are fairly constant (see Figure 5) with typical values being $m_{1.6-2.2} \sim 0.35$ mag and $m_{1.1-1.6} \sim 0.65$ mag. Thus, the 1.6-2.2 μm color excess is given by

$$E_{1.6-2.2} = -2.5\ log(\frac{f_{1.6}}{f_{2.2}}) + 0.175, \tag{1}$$

To translate the color excess into an extinction we assume that the extinction is in a foreground screen (i.e. not mixed with the stars) and use the extinction law derived by Rieke & Lebofsky (1985) that has been modified at the shorter wavelengths. This extinction law translated into the NICMOS filter bandpasses yields color excesses of $E_{1.6-2.2} \sim 0.079$ and $E_{1.1-1.6} \sim 0.191$ mag for $A_V = 1$ mag.[2] Therefore,

$$A_{2.2} = 0.100\ \frac{E_{1.6-2.2}}{0.079}, \tag{2}$$

$$A_{2.2} = -3.15\ log(\frac{f_{1.6}}{f_{2.2}}) + 0.222. \tag{3}$$

To obtain an image de-extincted at 2.2 μm,

$$f_{2.2}(true) = f_{2.2}(obs) \times\ exp(\frac{A_{2.2}}{1.086}). \tag{4}$$

The equivalent relations using the 1.1 and 1.6 μm bands to estimated the extinction at 1.6 μm is

$$A_{1.6} = -2.30\ log(\frac{f_{1.1}}{f_{1.6}}) - 0.105. \tag{5}$$

and an image de-extincted at 1.6 μm is obtained from

$$f_{1.6}(true) = f_{1.6}(obs) \times\ exp(\frac{A_{1.6}}{1.086}). \tag{6}$$

Equations 3-4 were applied to the 1.6 and 2.2 μm images, to yield 'de-extincted' 2.2 μm images for the galaxies. (In a few instances the 2.2 μm background variations or PSF artifacts severely corrupted the 2.2 μm image and we used equations 5-6 to obtain 'de-extincted' 1.6 μm images.) To avoid false color gradients in the ratio image used in Equation (3) (due to the higher resolution at 1.6 μm), we convolved both the 1.6 than 2.2 μm images to a common resolution ($0.2''$) before computing the extinction and applying to the 2.2 μm data (Eq. 4). In Figure 4, the de-extincted 2.2 μm and 1.1 μm (for reference) images are shown for each galaxy. In viewing these extinction-corrected images, the reader should bear in mind the two assumptions which are certainly not always correct: that the dust providing the extinction lies in front of the emission sources (i.e. is not mixed with the stars) and that the intrinsic (unextincted) color is uniform and approximated by that of a moderate age starburst population. The former is probably the most flawed of these assumptions. When the dust is mixed uniformly with the radiation sources, the observations typically sample the first few optical depths at each wavelength. For actual τ in the range 1 to 10 with the dust uniformly mixed with the stars, the true optical depth is underestimated typically by a factor ~ 2 but for larger τ the underestimate can be much greater (see Fig. 5 and Witt, Thronson, & Capuano 1992). The emission will also appear bluer than would be expected for the same total extinction. An additional problem arises from the intrinsically higher angular resolution at 1.6 μm than at 2.2 μm. Despite the reservations and assumptions noted above, these extinction corrected images probably yield a more generally accurate rendition of the intrinsic 2.2 μm emission than the observed 2.2 μm images. Evidence of this is provided in the case of Arp 220 where the de-extincted image yields peaks which better fit the PA of the radio nuclei (Scoville et al. 1998).

3. MORPHOLOGY

Morphological characteristics occuring in many of the images of the 24 galaxies include: double nuclei, extended 'tidal' tails, point source nuclei (particularly at 2.2 μm in the most luminous and distant objects), bright off-nuclei star clusters, spiral arms (on the scale of 100 pc to 1 kpc), and high reddening in the nuclei. These features are summarized in Table 3. In the following we briefly summarize the features seen in each object.

[2]Note that the NICMOS flux calibrations were determined using relatively blue stars. Thus, in the case of extremely red objects, the broad bandwidth of the F110W filter may result in an overestimation of their fluxes (e.g., by ~0.15 mag for an $A_V \sim 5$).

3.1. *NGC 4418*

The nucleus of this galaxy exhibits strong extinction along the galactic disk to within 100 pc of the nucleus which causes the short wavelength emission (1.1 μm) to be elongated perpendicular to the plane of the galaxy at small radii (see Fig. 3-4). The reddening is most easily seen in the ratio image in Fig. 3. Evans et al. (1999a) compare the near-infrared (NICMOS) morphology of the nuclear region with recently acquired mid-infrared (MIRLIN) images and discuss the possibility that the bulk of the luminosity of NGC 4418 emanates from a region obscured by a compact ($\sim$ 130 pc) stellar disk.

3.2. *Zw049.057*

Zw049.057 appears as a highly inclined disk with a smooth light distribution at large radii but a bright arm of star formation $\sim 1''$ south of the 2.2 μm peak (Fig. 2). The reddening and the extinction-corrected 2.2 μm emission also peak $\sim 0.5''$ south of the 2.2 μm emission peak (Fig. 3 and 4). Zw049.057 exhibits a linear 'shadow' feature extending radially from the nucleus along the minor axis at $PA \simeq -50°$ (see Fig. 2). The feature is perhaps due to an absorbing cloud in the nucleus blocking radiation along the shadow line on the minor axis. This interpretation would imply that much of the light seen along the minor axis of the galaxy is scattered light from the nucleus. Alternatively, if this is a dust absorption lane, it must extend *linearly* over 500 pc in radius and a high mass is required in order to produce the absorption over the extent of the lane.

3.3. *NGC 6090*

In the primary (NE) galaxy of NGC 6090, two distorted spiral arms are seen, both of which are delineated by a number of bright clusters. The companion, $6''$(3.4 kpc) to the SW could almost be an extension of one of the primary's spiral arms; however, the bright 2.2 μm point source at the one end of the secondary together with a radio continuum source argue for this being a less massive galaxy which is merging with the NE galaxy. The 2.2 μm extinction-corrected contour map (Fig. 4) strongly favors this interpretation since the SW galaxy clearly appears very substantial and has only a low level bridge to the spiral pattern of the NE galaxy. The area between the two galaxies contains a massive concentration of ISM as evidenced by the very red colors of the clusters (No. 6 and 8 in Table 7) on the SW edge of the primary galaxy and the fact that the mm-wave CO(1-0) emission peaks in this overlap region (Bryant & Scoville 1999). The morphology of NGC 6090 suggests an extended starburst triggered by the galaxy-galaxy interaction. The large number of luminous clusters seen along the side of the NE galaxy closest to the secondary galaxy suggests that the starbursts are triggered hydrodynamically (eg. cloud-cloud collisions or shocks from a high pressure, intercloud medium) rather than by large-scale gravitational force gradients. (Tidal effects should be equal on the near and far sides contrary to the observed asymmetry.) Dinshaw et al. (1999) present a more detailed description of these data, and conclude, in part, that the radio emission from NGC 6090SW is not coincident with the brightest near-infrared "knot", and that this knot may actually be a forground star.

3.4. *NGC 2623*

NGC 2623 has a highly reddened nucleus with a possible short tidal feature or spiral arm at $\sim 1''$ radius to the SW (seen best in the 1.1 μm image). In the optical, prominent tails are seen suggesting that this system underwent a significant merging event in the past (Toomre 1977, Joseph & Wright 1985). However, at 1.6 and 2.2 μm, the light profiles are smooth, following approximately an $r^{1/4}$ law (Wright et al. 1990 see below). The latter morphology suggests that the galaxies which may have merged have coalesced into a common nucleus. A weak VLBI radio core is seen in the nucleus of NGC 2623 (cf. Lonsdale, Smith & Lonsdale 1993). In CO(1-0) the emission complex is $\sim 1.6''$ in diameter with kinematic major axis E-W (Bryant & Scoville 1999), similar to the reddening distribution shown in Fig. 3.

3.5. *IC 883*

IC 883 (Arp 193) appears as a highly inclined disk with the reddening increasing to the NW within the disk. The peak in the extinction-corrected 2.2 μm light distribution coincides with the 2.2 μm flux peak but the centroid is clearly displaced to the northwest. The reddening distribution shown in Fig. 3 is similar to the CO(1-0) emission which has a size $4.1'' \times 2.2''$ elongated along the plane of the galaxy and with kinematic major axis in the same direction (Bryant & Scoville 1999). (The increase in apparent 2.2/1.1 μm color ratio on the NE of IC 883 is small and occuring at low flux flux levels; it may be due to flatfielding errors.) A number a bright clusters are seen above and below the disk out to $5''$ radius. Their high luminosity suggests that they are young ($\leq 10^9$ yrs; see below), implying that the galaxy may have undergone a collision in the past with a burst of star and cluster formation in spherical region before the ISM settled into its present disk-like configuration. The near-infrared morphology of IC 883 is very similar to that of M82 although the luminosity is scaled up by over an order of magnitude.

3.6. *NGC 7469*

The near-infrared emission from NGC 7469 is dominated by the bright, point-like Seyfert nucleus point-source. However, the bright inner disk of the galaxy has been seen in much earlier optical (De Robertis & Pogge 1986, Wilson et al. 1986) and near-infrared (Mazzerella et al. 1994) imaging, and is discussed extensively in Genzel et al. (1995). A short spiral arm-like feature in the NW are clearly seen in the point-source subtracted images (Fig. 3). (The bright linear SSE–NNW feature is a PSF artifact which we were unable to remove in the 2.2 μm image.) In the inner disk, there is a ring of star formation at $\sim 1''$ radius, corresponding to 500 pc. The structure within the ring is similar in all three bands and is well outside the area in which residual PSF should introduce structure. This starburst disk is very similar to that seen in NGC 1068; in NGC 7469 there is no evidence of a bar like that seen in NGC 1068. The secondary companion to NGC 7469, IC 5283 is $80''$ (26 kpc) away and therefore well outside the field of our images. The data for this galaxy will be discussed more thoroughly in Thompson et al. (1999).

3.7. *VV 114*

The two galaxies in VV 114 are sufficiently extended that a mosaic of two images was required to cover them both using the NIC2 camera. These galaxies present a remarkable contrast from the visual to near-infrared (cf. Knop et al. 1994; Doyon et al. 1995) – the eastern galaxy which is very insignificant in the visual becomes the dominant source in the near-infrared in terms of surface brightness. The western galaxy has a great number of luminous star forming regions in an arm running between the two galaxies and to its south. This positioning of the young clusters in the overlap region of the two galaxies is similar to that seen in NGC 6090. In the mm-wave CO line (Yun, Scoville & Knop 1995) and 850 μm continuum (Frayer et al. 1999), the major concentration of emission actually lies between the two galaxies . In the eastern galaxy, there are two 2 μm peaks, the brightest being that to the SW where the reddening is also greatest. A more detailed discussion of this galaxy is provided in Scoville et al. (1999a).

3.8. *NGC 6240*

The double nuclei in NGC 6240 are separated by 1.6″ N-S (0.8 kpc) and the southern nucleus is relatively brighter at long wavelengths. The reddening peaks to the north and slightly east of the southern nucleus. In the radio continuum, there are also two nuclei but their separation is only 1.4″(Carral et al. 1990). The mm-wave CO(2-1) emission peak is located between these nuclei (Tacconi et al. 1999, Bryant & Scoville 1999). In addition, the near-infrared CO-bandhead velocity dispersion of giant stars exhibits an increase between the nuclei (Tacconi et al. 1997), all of which indicate a significant mass concentration (perhaps largely interstellar gas) between the nuclei.

3.9. *VIIZw031*

Ground-based optical images have been used to suggest that VIIZw031 might be an elliptical galaxy (eg. Djorgovski et al. 1990; Sanders & Mirabel 1996) ; however, the NICMOS images clearly resolve extremely bright, asymmetric spiral arms in the nucleus. Numerous clusters are seen in the galactic disk and the reddening peaks to the east of the nucleus. While the NICMOS data clearly imply that this is a spiral system and strengthens the view that the progenitors of LIGs and ULIGs are composed of at least one spiral galaxy, it is not obvious what triggered the activity occuring in VIIZw031. There is no evidence to date of a nearby interacting companion galaxy (premerger) or tidal tail remnants (post-merger).

3.10. *IRAS 15250+3609*

In IRAS 15250+3609 there is one dominant nucleus and a much less bright (possible) nucleus 0.7″ SE. It is not clear if this second source is indeed a nucleus or an anomalously bright cluster but its colors are very red like most of the nuclei in our sample and it is approximately a factor of ten more luminous than any other cluster in this system. The emission associated with the primary nucleus is also extended in the direction of the secondary source. In addition, the nuclear region is surrounded by several bright star clusters.

3.11. *UGC 5101*

UGC 5101 (IRAS 09320+6134) shows a single nucleus with surrounding spiral isophotes that rotate in PA as a function of radius. Its nucleus is unresolved at 2.2 μm and extremely red. In the color-color diagrams (Fig. 5-5), the nucleus is anomalous in being the only one of the cold ULIGs with colors similar to warm ULIGs (possibly indicating an AGN source). In the optical, an extended edge-on tidal tail is seen like that in Mrk 273 (see Sanders et al. 1988a, Surace et al. 1999b), while a second tail loops around the nucleus in a nearly complete ring. A number of clusters can be seen in the northern arm and the reddening increases just to the north of the nucleus. Due the bright galactic background near the nucleus, we were not able to accurately fit and subtract a PSF from the 2.2 μm image and the SW–NE stripe is a residual PSF artifact.

3.12. *IRAS 10565+2448*

The primary galaxy in IRAS 10565+2448 is much more luminous than the companion galaxy, located near the edge of our images 8″ to the SE. Nevertheles, it appears that the two are interacting given the bridge between them (see Fig. 2) and their angular separation which corresponds to only 6.7 kpc. A third galaxy and tidal tail is seen to the NE of the primary, but out of the field of view of our NICMOS images (Murphy et al. 1996).

3.13. *IRAS 08572+3915*

The two nuclei in this system are separated by 5″, corresponding to 5.6 kpc. The northern nucleus is unresolved in all three bands and an extremely bright cluster is seen to the SE of the nucleus (Fig. 2). The low level common envelope of the system which is best seen in the contour images (Fig. 3-4) bridges the region between the galaxies at 1.1 and 1.6 μm and extends well to the east of the southern galaxy. (The disappearance of the envelope in the 2.2 μm image in Fig. 3 is probably due to the higher background and lower sensitivty at 2.2 μm.)

3.14. *IRAS 05189-2524*

This galaxy shows a single unresolved nucleus in all three bands. In the PSF-subtracted images used in Fig. 3, low level emission is seen to at least 3″ radius. The nuclear source is extremely red (see Fig. 3). (The sharper extensions E-W and to the N in the 2.2 μm image of Fig. 3- 4 are probably due to incomplete PSF removal.) At optical wavelengths (Surace & Sanders 1998,1999), this galaxy has a nucleus which appears to be bisected by a dust lane; the longer wavelength NICMOS data clearly penetrates this dust. The optical images also exhibit a "plateau" of extended blue star formation surrounding the nucleus which may correspond to the extended light seen in the NICMOS data, as well as several extended tidal loops.

3.15. *IRAS 22491-1808*

This spectacular system has two nuclei separated by 1.6″ (2.4 kpc), which were first observed by Carico et al. (1990b). Many extremely luminous clusters and two high surface brightness tidal tails are seen extending to E and NW. The western nucleus is unresolved in all three bands. Optical imaging reveals so many luminous star clusters as to prevent identification of the actual nuclei; near-infrared

data are required to locate them (Surace 1998, Surace et al. 1999b). The optical images also reveal that the full extent of the tails, which terminate in complex loops. Many of the clusters seen by NICMOS are embedded in these tails, particularly the one to the NW.

3.16. *Mrk 273*

The northern nucleus is both bluer and more spatially extended than the redder, unresolved southern nucleus. Both nuclei are much redder than the surrounding galaxy. The tidal tails may be seen in both the 1.1 μm emission and in obscuration (2.2/1.1 μm) extending well to the north and south of the nuclei. In addition, several bright clusters are seen to the south and north of the northern nucleus. Optical imaging shows the presence of a northern tidal loop as well as an edge- on tidal feature to the south (Sanders et al. 1988a). Additional optical and UV imaging shows the presence of young star formation in the northern nucleus and in a region directly to its west (Surace 1998). Knapen et al. (1997) discuss the relation of their adaptive optics near-infrared data to their radio data. Surprisingly, they find that the northern nucleus is the strongest radio source and associate it with the active nucleus which is presumably the source of the known Sy 2 emission (Sanders et al. 1988a), while they find the dominant infrared peak (the SW nucleus) to be the location of a starburst, which is the opposite of what is implied based on the NICMOS morphology. A near-infrared source SE of the northern nucleus is also shown which had been known previously (Condon et al. 1991). While Knapen et al. present this as a background object, the NICMOS data shows it is spatially coincident with a blue compact object identified as a star cluster.

3.17. *Arp 220*

This merging system contains two nuclei in both the radio continuum and the near-infrared separated by $0.95''$(350 pc projected separation). A detailed discussion of the NICMOS data on this galaxy is given in Scoville et al. (1998). In the data, extremely high reddening gradients are seen to the south of the brighter western nucleus and to the south of the eastern peak seen in the 1.1 μm images (Fig. 3). In fact, the extinction is so high on the east that in the extinction-corrected image (Fig. 4), the eastern peak which we identify with the eastern nucleus lies well to the south of the 1.1 μm peak, between this peak and a weak third peak seen in the 2.2 μm image. The strong obscuration to the south of the western peak can be interpreted as an inclined dust disk ($i \simeq 30°$) embedded in the nuclear star cluster (Scoville et al. 1998). The light which escapes the cluster can appear crescent-shaped if the disk is of size comparable to (or smaller than) the cluster and embedded within the cluster.

3.18. *PKS 1345+12*

The western nucleus in PKS 1345+12 is unresolved in all three bands and much redder than the eastern nucleus (see Fig. 3). The eastern nucleus is clearly resolved and extended. The common envelope for the two nuclei is extended in the east-western direction, as well as to the south. Evans et al. (1999b) compare the near-infrared (NICMOS) data with radio data and recently acquired CO(1 $\rightarrow$ 0) interferometry to show that the molecular gas and radio jets of PKS 1345+12 are associated with the redder nucleus, and thus that the molecular gas is the likely source of fuel for the imbedded, radio-loud AGN.

3.19. *IRAS 12112+0305*

The two well-separated nuclei in this system were first observed by Carico et al. (1990b), and are apparently connected by a bridge of emission, and a tidal tail $4''$ SW of the southern nucleus. The northern nucleus is crescent-shaped (like that in Arp 220) and this may indicate the presence of an embedded opaque dust disk (see above). The southern nucleus becomes increasingly point-like at the longer wavelengths and both nuclei are much redder than the surrounding galaxy (see Fig. 3). Optical imaging reveals a northern counter-tail (Surace et al. 1998b) while ultraviolet imaging reveals the presence of significant obscuration along the line of sight to the southern nucleus, as well as young star-forming clusters embedded in the southern tail (Surace & Sanders 1999c).

3.20. *IRAS 14348-1447*

This system has two well-separated but clearly interacting spiral galaxies – a curved tidal tail with embedded clusters can be seen to the NE of the northern galaxy and a less extended, fainter tail is seen to the SW of the southern galaxy. The southern nucleus has a ring of star clusters to its northwest and southwest; these are best seen in optical images (Surace 1998) and do not readily appear in the NICMOS data, which is indicative of their young age.

3.21. *IRAS 17208-0018*

IRAS 17208-0018 is the most luminous galaxy in our sample that shows no direct evidence of an AGN – the optical emission line ratios are HII-like, the nucleus in the near-infrared images is extended in all bands, and the inner disk at $R \leq 1$ kpc shows numerous extremely luminous clusters. The same region has very strong reddening gradients – it is quite likely that even at 2.2 μm, dust is still masking the nucleus. The outer disk of the galaxy appears very disturbed (best seen in the 3-color image, Fig. 2).

3.22. *IRAS 07598+6508*

The broad-band emission in all three filters is dominated by the point-source nucleus but low level emission can also be seen out to $\sim 2''$ radius. Optical *HST* images reveal the presence of luminous blue star clusters to the south and east (Boyce et al. 1996), and it is unclear if the extended emission is due to these clusters or to the underlying host galaxy.

3.23. *Mrk 1014*

Although dominated by the QSO nucleus, point-source subtraction clearly shows twisting spiral isophotes within the central 4 kpc, indicating either a starburst spiral disk or tidal debris (see Fig. 3). Similar features are seen optically in the inner nuclear regions (Surace et al. 1998). Wide-field deep optical imaging reveals a tidal arm extending to the NE over a distance of 60 kpc (MacKenty & Stockton 1984) which has many embedded star clusters (Surace 1998), which are too blue to see here.

3.24. *3C48*

In 3C48, the emission in all three bands is dominated by the unresolved quasar nucleus; however after point-source subtraction (see Fig. 3) extended emission can be seen (particularly at 1.6 μm) to the NE and S of the nucleus. These extensions correspond to those seen in the optical and K-band by Stockton & Ridgway (1991); they identify the NE source and the nucleus of the galaxy merging with the QSO host galaxy. (3C48 was not included in Fig. 4 since the ratio image is severely contaminated by the PSF artifacts at 2 μm).

4. NUCLEAR BARS AND SPIRALS

It is often suggested that nuclear bars or spiral structure made aid in the loss of angular momentum from the gas and hence lead to high rates of radial accretion to feed nuclear activity (e.g. Schlosman, Frank & Begelman 1989). The high resolution NICMOS images of our galaxy sample provide some constraints on such structures. In Table 3, 10 of the galaxies are listed as having spiral-like structures in the inner kpc and in most cases these spiral arms continue into $\leq$ 100 pc radius. In no cases did we find evidence of an obvious nuclear bar on similar scales; however, it must be recognized that most of these systems are sufficiently disordered due to variable extinction and starburst activity that an underlying bar in the older stellar population would probably be difficult to detect even if it were there. This is in agreement with Regan & Mulchaey (1999) who used optical and near infrared HST imaging for a sample of nearby AGN to look for small scale nuclear bars in reddening distributions. Only 3 out of 12 Seyfert galaxies in their sample exhibit nuclear bars.

5. FLUX MEASUREMENTS

Measurements of the magnitudes at 1.1, 1.6 and 2.2 μm were made for each galaxy in 1.1, 5 and 11.4$''$ diameter circular apertures centered on the nucleus using the IPAC routine SKYVIEW (note that the 1.1$''$ aperture was used in order to include the first Airy ring of the NICMOS PSF). The resultant magnitudes are listed in Tables 3 and 4. For six of the galaxies with well resolved double nuclei, both galactic nuclei were measured. In addition to the aperture measurements, the magnitudes of the nuclei were determined by subtracting the contribution from the underlying stellar light (i.e., the adjacent pixels) from the measured 1.1$''$ nuclear apertures. The results are listed in Table 5.

All compact (cluster) sources outside the nuclei were measured in a 0.53$''$ diameter aperture using Source Extractor (Bertin & Arnouts 1996), and the results are tabulated in Table 7 for all sources with a signal-to-noise ratio greater than 3.0 in all three bands. As was the case with the nuclear magnitudes, the local background of every cluster was subtracted based on a sampling of the adjacent emission.

5.1. *Color-Color Diagrams for Galaxies*

In Figures 5-7, the $m_{1.1-1.6}$ and $m_{1.6-2.2}$ colors of the galaxy sample are plotted for the nuclei with symbols denoting the infrared luminosity and 'warm/cool' classification (Table 5), with symbols denoting the optical emission-line classification, and for a fixed 2 kpc-diameter aperture (Table 6) with symbols denoting the infrared luminosity and 'warm/cool' classification. Also shown in the figures are the expected colors for an instantaneous starburst model (Salpeter IMF with masses ranging from 0.1 – 125 $M_{\odot}$and solar metallicity) as it ages (Bruzual & Charlot 1993). In this model, the colors change rapidly during the first 10^7 yr but after that they are relatively constant out to 5×10^8 yr. The mean color of optical bright PG QSOs (Sanders et al. 1988b) is shown by the cross and the dotted lines shows the effect of additional emission by hot dust with increasing contributions at 2.2 μm. It is important to note that the near-infrared SED of the PG QSO probably already has contributions due to hot dust and these curves represent an arbitrary increase in the relative dust contributions, not a new generic component (Barvainis 1987). The color of free-free emission is shown and the effects of differing amounts of extinction is indicated by the reddening vector in the lower left of the figures. The reddening vector was calculated from the extinction curve of Rieke & Lebofsky (1985) and Whittet et al. (1998) assuming a foreground dust screen. For comparison, the reddening path for extinction by dust mixed uniformly with the stars is also shown (the curved track). Both the model fluxes and the extinction curve were convolved with the NICMOS filter bandpasses. The models were also redshifted to z= 0.05, corresponding to a typical redshift of the galaxies observed here.

The salient features of the color-color diagrams are :

1) Virtually all of the galaxies are redder in both $m_{1.1-1.6}$ and $m_{1.6-2.2}$ than the unreddened starburst colors (i.e. they lie well above and to the right of the starburst evolutionary track, see Fig. 5). Their colors clearly require either extincted starlight and/or an AGN energy source. This general trend has been observed in ground-based near-infrared data as well (e.g. Sanders et al. 1988a; Carico et al. 1990; Mazzarella et al. 1992).

2) Both nuclei of Arp 220 and the nucleus of IR 17208-0018 are observed to have the most extreme $m_{1.1-1.6}$ colors of all of the galaxies in the sample. Thus, if the near-infrared light is associated with the source of the bolometric luminosity, then the nuclear power sources in these two galaxies are well buried even at near-infrared wavelengths.

3) The warm ULIGs (IRAS 05189-2524, IRAS 07598+6508, PKS 1345+12, Mrk 1014 IRAS 08572+3915, and 3C 48) are all much redder in $m_{1.6-2.2}$ than $m_{1.1-1.6}$ relative to a typical cold ULIG or a PG QSO (see Fig.. 5), consistent with similar analyses done with ground-based observations (e.g. Surace et al. 1999) . These colors for the warm ULIGs are hard to account for by reddened starlight. The very red $m_{1.6-2.2}$ color is probably due to substantial contribution at 2.2 μm by warm dust emission (at 600-1000 K).

4) On average, the nuclear colors of the cold ULIGs are redder than those of the less-luminous cold LIGs (see Fig.. 5). Of the three ULIGs that contain at least one nucleus similar in color to the LIGs (IR 08572+3915S, PKS 1345+12E, and IR 22491-1808W), this nucleus is significantly bluer than the other. The two LIGs observed to have extremely red colors (comparable to Arp 220) are IC 883 and NGC 2623.

5) The nuclei in VV114E and UGC 5101 have near-infrared colors which place them in the area of the color-color diagram occupied by warm ULIGs despite the fact

that their mid-infrared colors are cold (note that the extremely red colors of VV114E have been previously discussed by Knop et al. 1994). Their nuclear colors (Fig.. 5) could be explained by the dust mixed with stars model, but it would require >> 50 magnitudes of visual extinction. The underlying galaxy-subtracted nuclear colors of Arp 220E, Mrk 273S, and IR 17208-0018 (Table 5; Fig.. 5) also place these galaxies in the warm galaxy section of the plot, but require a 60–70% contribution to the 2.2 μm light by 1000K dust. Mid-infrared spectroscopy with ISO revealed high ionization state emission lines in Mrk 273 (Genzel et al. 1998), but it likely that these lines emanate from the northern nucleus. These may be examples of galaxies having substantial starbursts together with AGNs.

6) On average, the ULIGs that are optically classified as seyferts are redder (in $m_{1.6-2.2}$) than the HII region-like galaxies (Fig.. 6. With the exception of IR 08572+3915S, the LINERs appear to be dispersed over the region redward of $m_{1.1-1.6} = 1.5$ and $m_{1.6-2.2} = 0.5$.

7) In the 2 kpc-diameter aperture measurement (Fig. 7), the cold ULIGs and the LIGs move back toward the starburst models with a few magnitudes of visual extinction. The outer ULIG regions are thus consistent with simple star formation models with reddening corresponding to $A_{\rm V}$ of a few mag., assuming a foreground screen of dust.

5.2. *Color-Color Diagram for Clusters*

In Fig. 8 the $m_{1.1-1.6}$ and $m_{1.6-2.2}$ colors are shown for all of the measured clusters which have $SNR \geq 5$ in all three bands. While there is a large spread in both colors, most of the clusters have $m_{1.1-1.6} < 1.5$ mag and $m_{1.6-2.2} < 1.0$ mag. The majority are consistent with young star clusters (ages between 5 and 300 Myr) which are reddened by up to 3 magnitudes of visual extinction. The majority of the cluster sources have colors implying much lower reddening than the galactic nuclei (compare Figs. 5 and 8). Some of this is due to the fact that the clusters are most easily detected outside the nucleus where the dust extinction is less. The cluster extinction is also likely to be better-characterized by a foreground-screen model since it is unlikely there is much dust *inside* the clusters (cf.Whitmore & Schweizer 1995).

The observed magnitudes of the clusters can be used to crudely estimate their bolometric luminosities and masses with some simplifying assumptions. First, the instantaneous starburst models (described earlier) exhibit steeply rising near-infrared fluxes up to 10^7 yrs, at which point the 1-2.2 μm fluxes change relatively slowly out to 10^9 yrs. This is due to the dominance in the near-infrared of red supergiants from the starburst. Secondly, most of the cluster formation was probably triggered *dynamically* by galactic interaction and merging over a time $\geq 3 \times 10^7$ yrs. The combination of these two *reasonable* assumptions, implies that most of the observed clusters are likely to be of age 10^7–10^8 yrs – a period during which the colors are relatively constant and the bolometric corrections to convert from 1.6 μm fluxes to bolometric luminosity are also relatively constant. For For ages of $3 \times 10^6, 10^7, 10^8$ and 10^9 yrs, the 1.6 μm bolometric corrections are -3.5, +0.45, +0.67 and +1.7 mag respectively (Bruzual & Charlot 1993). For the estimates below, we simply adopt a fixed bolometric correction for the 1.6 μm band (i.e. M_{bol}=$M_{1.6}$+0.6 mag), and assume no reddening. The absolute $\mathbf{M_{1.6}}$ are in the range -14.89 to -19.01 mag for the first-ranked clusters (Table 7). The derived bolometric luminosities of the brightest clusters range from 4×10^7 to $2\times10^9 L_\odot$ with a median value of $4\times10^8 L_\odot$.

The BC95 (Bruzual & Charlot 1993: an updated version called BC95 is used here, private communication) model for an instantaneous starburst with a Salpeter IMF between 0.1 and 125 $M_\odot$ can then be used to estimate the required cluster mass from the 1.6 μm absolute magnitudes. At a typical age of 5×10^7 yrs, the luminosity to mass ratio of these models is 15 $L_\odot$ / $M_\odot$ yielding mass of the first-ranked clusters in the range 3×10^6 to $1\times10^8 M_\odot$ with a median value of 3×10^7 $M_\odot$. If the clusters were older than assumed above, the implied masses are of course greater. And for an IMF tuncated on the low mass end at $2.5 M_\odot$ (instead of $0.1 M_\odot$), the dervied masses are typically a factor of 3-4 less. For comparison, Galactic globular clusters have typical masses $\sim 10^5 M_\odot$(van den Bergh 1995) and even if the clusters seen here have a truncated IMFs, the inferred masses are well in excess of those expected for globular clusters. The clusters seen in the infrared luminous galaxies must therefore be super-massive compared to known globular clusters and/or be unresolved associations of many globular clusters. The very high masses implied by the assumption of a standard IMF extending to 0.1 $M_\odot$ strongly suggest that the IMF cutoff at a higher mass. This is similar to the conclusion derived from optical imaging by Surace et al. (1998) based on the measured sizes and brightnesses of the clusters in HST optical images.

6. RADIAL DISTRIBUTIONS

The degree of nuclear concentration of the light as a function of wavelength, luminosity and galaxy type (i.e. optical spectral class or IR warm vs cold colors) can provide important clues to the luminosity source and evolutionary state of the galaxies. In this section, we first discuss the radial surface brightness distributions before quantifying the central concentrations in terms of the half-light radii.

6.1. *Surface Brightness*

For each of the galaxy images, the radial surface brightness profile was computed from the mean brightness of pixels within each radial bin. In Figs. 9, the surface brightness (Jy arcsec^{-2}) is shown as a function of angular (top scale) and linear radius (bottom scale) for each galaxy. In view of the irregular morphologies of most of these galaxies, we did not fit elliptical isophotes to the image data but instead just adopted the apparent (projected) radius for these plots. The dynamic range from peak to the level of undetectable emission is typically three orders of magnitude. In VV114 where there are two well-separated galaxies of comparable magnitude, a radial profile was done separately for each galaxy; in the other cases only one profile was measured from the 2.2 μm peak position. In systems with two galaxies, the radial profiles show a second peak simply due to the secondary galaxy (eg. IRAS 12112+0305 and IRAS 14348-1447).

Comparison of the light profiles in the three bands clearly shows that in virtually all cases (except VV114W) the 2.2 μm flux (solid line in Figs. 9) is more centrally

peaked at the nucleus than that at 1.1 and 1.6 μm (dotted and dashed lines). Throughout most of the galaxies, the absolute value of the surface brightness in Jy arcsec^{-2} is also higher at the longer wavelengths. The relative flux variations imply the stellar light must be highly reddened by dust. Moreover, both the dust and the youthful population must be concentrated at smaller radii. For the starburst population described in §2.3, the colors are $m_{1.6-2.2} \sim 0.35$ mag and $m_{1.1-1.6} \sim 0.65$ mag after $5{\times}10^7$ yrs which corresponds to $f_{1.6}/f_{2.2} \sim 1.18$ and $f_{1.1}/f_{1.6} \sim 0.97$. Since these colors are approximately the reddest obtained in the starburst models, the observed colors, with long wavelength fluxes exceeding the shorter wavelength, necessitate substantial reddening and cannot be attributed solely to a youthful stellar population.

In NGC 4418 and VIIZw031, the outer regions of the galaxies have apparently lower surface brightness at 2.2 μm than in the 1.1 and 1.6 μm bands; however, this occurs at low flux levels where variations in the 2.2 μm background may be responsible. In VV114W the higher flux at shorter wavelengths occurs at higher flux levels and clearly real.

6.2. $\mathbf{R^{1/4}}$ *and Exponential Disk Radial Profiles*

Since it has been postulated that ULIGs may evolve into elliptical galaxies once the starburst subsides and the gas is either used up or expelled in a wind (Sanders et al. 1988a; Heckman, Armus & Miley 1990) the stellar surface brightness profiles of ULIGs might shed light upon their evolutionary state. To measure the stellar light distribution in dusty systems, it is wise to go to the longest possible wavelengths, while still avoiding significant contamination from warm dust. Thus the near infrared is the ideal wavelength at which to measure the distribution of stars in ULIGs and compare the average profiles to models fitting broad classes of elliptical or spiral Hubble types. Schweizer (1982) first showed that elliptical-like light profiles could be seen in a merging system, in this case NGC 7252 in the V-band, and thus provide strong evidence for relaxation of the stellar population and eventual evolution into an elliptical galaxy. Among the first to perform this experiment for LIGs and ULIGs were Wright et al. (1990), who noted that the near–infrared K-band surface brightness profiles of Arp 220 and NGC 2623 could be well fit with a de Vaucouleurs r$^{1/4}$ law (i.e. $\log\Sigma \sim$r$^{1/4}$) over reasonably large radii ($\sim 0.5-4$ Kpc for Arp 220 and $\sim 0.8-4$ Kpc for NGC 2623). It is important to note that both Arp 220 and NGC 2623 could also be well fit by exponential (spiral-like) surface brightness profiles, but only over a smaller range in radii ($\sim 2-4.5$ Kpc for Arp 220 and NGC 2623).

The superior resolving power and sensitivity to small–scale features that is possible with NICMOS makes an exploration of the radial surface brightness profiles of the galaxies in our sample worthwhile. We show the 1.6μm logarithmic surface brightness profile for each galaxy as a linear function of radius in Fig. 9. Here, a straight line fit would suggest a spiral-like stellar profile. Similarly, we show the 1.6μm logarithmic surface brightness for each system as a function of r$^{1/4}$ in Fig. 10. An r$^{1/4}$ law profile will appear as a straight line in this figure. To evaluate quantitatively the r$^{1/4}$-law and exponential-disk models, minimum χ^2 fitting of both models to the observational data was done and Table 8 summarizes the results. The radial range for the fitting was between 0.22$''$ radius and the outer limit of detectable emission (typically a factor of 30 in radius). All model fitting was performed on the 1.6 μm data (as opposed to the 2.2μm data) in order to take advantage of the greater sensitivity of NICMOS at 1.6μm. (Because the 2.2μm fluxes are less reliable in the faint, outer regions of the galaxies, we also did not use the extinction-corrected surface brightness.)

In 9 of 24 galaxies, the light profiles at 1.6 μm are fit better, (in the sense that the ratio of the χ^2 from the two fits is greater than three) by an r$^{1/4}$-law than by an exponential disk profile. These galaxies are NGC 4418, Zw049.057, NGC 2623, IC883, NGC 6240, UGC 5101, IRAS 10565+2448, Arp 220, IRAS 14348-1447. Several of these galaxies have been recognized in previous work as exhibiting an r$^{1/4}$ law : NGC 2623 (Wright et al. 1990; Standford & Bushouse 1991), IC883 (Standford & Bushouse 1991), and Arp 220 (Wright et al. 1990) and the scale lengths derived here (see Table 8) are similar to those derived previously by these authors. In the case of NGC 2623, the exponential disk form becomes acceptable if the nucleus is excluded. It is important to note, that the majority of the systems studied here (13 of 24) could be fit equally well by either an r$^{1/4}$-law or an exponential profile over the radii we are exploring with NICMOS. In only in one case, VV114E, was an exponential fit significantly better than an r$^{1/4}$-law fit. We also find that 8 of the 9 galaxies fit well by the r$^{1/4}$-law have cool IRAS colors (or equivalently have HII-like optical emission lines) while only one is warm. This correlation might arise since the cool ULIGs have more extended far infrared emission from an extended starburst population. The young stars, formed in a dynamically relaxed merger, eventually evolve to become bright in the near-infrared – possibly resulting in an r$^{1/4}$-law near-infrared light distribution.

Our admittedly small statistics seem to indicate for those ULIGs and LIGs where a clear preference is shown for one type of fit over the other, this is usually an r$^{1/4}$-law profile. Since our measurements cover a large range in radii for each source, and extend well beyond a typical spiral bulge radius in nearly all cases, this result is not simply stating the obvious fact that merging spiral galaxies have elliptical-like bulges. Instead, it suggests that the stellar population whose light dominates the inner $5-10$ Kpc in these galaxies appears to be better approximated by a spheroidal as opposed to a disk-like orbital configuration. If the near–infrared light is dominated by young stars such as red supergiants, these stars must have formed during the merger and have already assumed elliptical-like orbits. Whether these systems end up forming giant ellipticals will depend on a number of factors – most importantly, the overall mass density of stars in the central regions and the quantity of ISM left over in a cold disk after the merging is complete. Kormendy & Sanders (1992) have pointed out that in some of the ultra-luminous sytems (eg. Arp 220), the central mass density is in fact similar to the of elliptical galaxy cores if the massive ISM component is included – the presumption is then that an elliptical galaxy could be the end product if a significant fraction of the ISM is converted into stars. However, these are extreme examples and it seems more likely that the lower lumi-

nousity infrared, merging galaxies will end up as spirals with massive central bulges.

7. CURVE OF GROWTH AND HALF-LIGHT RADII

The change in color and/or the degree of compactness in the light distribution of a galaxy can provide important clues as to the dominant energy source. An active galaxy (Seyfert or quasar) can emit a significant fraction of its energy at all wavelengths on very small scales (tens of pc or smaller), whereas this is impossible for a starburst. The more luminous a system is, the harder it is to pack the requisite number of young stars and supernovae into a small enough volume without disrupting the starburst completely via the action of stellar and supernovae-driven winds. Although star formation in luminous infrared galaxies is believed to occur over relatively small (as compared to an entire galaxy) scales, sizes of a few hundred parsecs to a few Kpc have been measured from CO and emission–line gas observations. Since most of the energy in luminous and ultraluminous infrared galaxies emerges in the mid and far–infrared, this is the logical part of the spectrum from which to judge the size of the power source. A number of authors have presented mid–infrared images or estimates of the compactness at 10μm in some of the nearest LIGs and ULIGs with beams ranging from $2-10''$ (Becklin & Wynn-Williams 1987; Matthews et al. 1987; Carico et al. 1988; Sanders et al. 1988a, etc.) and have found a strong trend toward increasing compactness for systems with luminosities above $\sim 10^{11-12}$L$_\odot$. However, since the nearest ULIG (Arp 220) has a scale approaching 300pc/$''$, these observations, with the exception of the drift–scan measurement of Mrk 231 by Matthews et al. (1987) which did place an upper limit of $0.5''$ FWHM on the size of the emitting region in Mrk 231, could not rule out dense, luminous starbursts as the source of the enormous energies.

In the near–infrared, we are measuring starlight, hot dust, and/or non-thermal emission from a central active nucleus. Therefore we may not be directly probing the material responsible for the far–infrared emission in LIGs or ULIGs. However, the sharp and relatively stable PSF provided by NICMOS can be used to place a limit on the maximum amount of unresolved near–infrared light coming from the nucleus in each of our sample galaxies, and allow us to measure the compactness of these sources on scales often well below 100 pc. If a significant fraction of the total near–infrared light is unresolved at NICMOS resolution, it may provide strong evidence for an active nucleus.

In this section, we quantify the degree of central concentration of the light in the luminous and ultraluminous infrared galaxies in order to investigate trends in the nuclear contribution as a function of luminosity, merger evolutionary stage and nuclear characteristics. To accomplish this, in a manner which is relatively independent of distance effects, we compute the total flux with 3 kpc projected radius of the 2.2 μm peak and then calculate the percentage of this flux contained as a function of radii less than 3 kpc (Fig. 11). These curves of growth can then be used to assess the contribution of a compact source (i.e., a puatative AGN) to the total flux. The vertical bar on the top border indicates an angular *radius* of $0.12''$, corresponding to the radius (HWHM) of the diffraction resolution at 2.2 μm.

Inspection of Fig. 11 reveals that seven of the galaxies have a significant percentage ($\geq$ 30%) of their flux originating within $\sim 0.12''$ radius : NGC 7469, IRAS 08572+3915, IRAS 05189-2524, PKS1345+12, IRAS 07598+6508, Mrk 1014, and 3C48 (not shown here). All of the seven galaxies with significant nuclear point-source contributions are also classified as warm in terms of their mid-infrared colors, yet there are warm galaxies which do not exhibit significant point-like nuclei (eg. NGC 4418). Similar conclusions can be drawn with respect to the optical spectral classification – i.e. most of the galaxies with nuclear point sources contributing significantly in the near-infrared are classified as Seyfert or QSO, yet not all of the galaxies with AGN-like spectra have significant nuclear point sources at the resolution of these data. Although these qualitative correlations are not unexpected, it should be underscored that we are here finding that, quantitatively, a significant fraction of the flux in the near-infrared is nucleated in these seven sources. At the same time, it is important to recognize that even in those galaxies with strong point-like nuclei, there is usually also a similar contribution from a component which is clearly extended. Since it would be very difficult to have this extended component actually be scattered nuclear light, this extended flux is almost certainly stellar in nature. The half-light radii and mid-infrared color classifications are given for the entire sample in Table 9.

A visual summary of the near–infrared nuclear concentration of our sample LIGs and ULIGs is provided by Fig. 12 which shows the radii ($R_{1/2}$) in which 50% of the total flux (at $R \leq$ 3kpc) is enclosed for all of the galaxies as a function of their far-infrared luminosities, for both the 1.1μm and 2.2μm data. (These half-light radii are not correlated with distance of the galaxies and hence, the measured variations are real.) As described above, nearly all of the compact galaxies, those with R$_{1/2}$ < 0.5 Kpc, are warm (or equivalently have AGN or LINER optical emission line classifications), although there are a few cold systems (IRAS 12112+0305, NGC 2623, Zw049.057, and UGC 5101) that are nearly as compact at 2.2μm. As a group, the cold systems show a much larger spread in R$_{1/2}$ than do the warm systems. Figure 12 also clearly demonstrates that there is no correlation between the total far-infrared luminosity and the presence or absense of a significant nuclear point-source in the near-infrared.

Lastly, it is worth noting that R$_{1/2}$ is generally smaller at 2.2 μm than at either 1.1 or 1.6 μm. This is demonstrated in Fig. 13 which shows the ratio of R$_{1/2}$ in each band. In virtually all cases, the 1.1 or 1.6 μm sizes are similar and their ratio is tightly clustered near unity while the ratio of the 2.2 to 1.1 μm sizes is typically ~ 0.6 with a larger range. (The three exceptions are all systems where the nuclear point source is dominant and the larger size at 2.2 μm is simply due to the larger PSF size at longer wavelengths.) The smaller sizes of the cores at 2.2 μm are very likely due to the large dust extinctions at shorter wavelengths which lead to an underestimation of the true nuclear emission component. The nuclei are systematically much redder in color than the inner galactic disks.

8. THE NATURE OF THE EXTENDED NEAR-INFRARED LIGHT

Both the analysis of the galaxy colors and light profiles suggest that much of the near-infrared light from the cold galaxies is stellar in origin. While ground-based, near-infrared spectroscopy of luminous infrared galaxies shows evidence for a mixture of red supergiant light, emission from hot dust, and possibly a metal-rich giant population (Ridgway, Wynn-Williams & Becklin 1994; Goldader et al. 1995; Shier, Rieke & Rieke 1996), the high surface brightness of the nuclei relative to the underlying galaxy at 1–2 μm and the size of the slits used for the near-infrared spectroscopy ($3''$) indicate that the strong CO absorption often seen is likely coming from the nuclei only (Armus et al. 1995).

Regardless whether or not the extended light comes from stars produced as a result of the merger, recent 8–25 imaging of two galaxies in the sample provide strong evidence that only the high surface brightness nuclear features observed in the near-infrared contribute significantly to the overall bolometric luminosity of these galaxies. Mid-infrared observations by Soifer (1998) show conclusively that the 25 μm flux of Arp 220 is produced within the nuclear region containing the two nuclei, and Evans et al. (1999a) conclude that the 8–25 μm emission in NGC 4418 is compact, indicated that most of the bolometric luminosity of the galaxy is coming from a region $\leq 0.5''$ in diameter. Thus, the starlight or AGN responsible for heating the dust in these galaxies resides in the compact nuclear regions, which in many cases, are just becoming visible at near-infrared wavelengths.

9. CONCLUSIONS

The high resolution HST-NICMOS images presented here for a sample of 24 luminous infrared galaxies have revealed extremely diverse morphology, probably reflecting their varying stages of galactic merging/interaction and evolution. Eleven of the 24 systems exhibit double nuclei with projected separations between 0.4 and 7 kpc. Eleven of the 24 systems also have point-like nuclear sources and in 7 of these galaxies, the nuclear sources produce a significant fraction ($\sim$ 50%) of the total near-infrared flux. All but one of the systems with significant nuclear sources is classified as warm based on their mid-infrared colors. These 7 galaxies also possess nuclei with red near-infrared colors indicative of QSO light mixed with varying amounts of hot dust. With the exception of UGC 5101 and VV114E (and possibly three others), all of the cold galaxies have nuclear near-infrared colors consistent with reddened starlight.

The bright clusters seen in virtually every one of these galaxies have near-infrared colors consistent with ages $\geq 5 \times 10^7$ yrs and their luminosities range up to 2×10^9 $L_\odot$. In a few cases, they are preferentially situated along the area of overlap of the two galactic disks (eg. NGC 6090 and VV114) and were therefore probably formed by hydrodynamic gas compression of the ISM. Their masses are typically a factor of 100 greater than Galactic globular clusters and therefore they are not simply young globular clusters.

The relative contributions of AGNs and starlight to the near-infrared luminosity varies among the sample galaxies. The 7 systems with significant nuclear point-sources are likely to have significant AGN contributions since they also have optical emission line ratios characteristic of a hard-spectrum ionization source. On the other hand, for the rest of the sample, most of the near-infrared flux clearly originates outside the central 100-300 pc, and even in those systems with significant nuclear sources there is still approximately 50% of the near-infrared emanating from a spatially extended stellar population.

Nine of the 24 systems exhibit an *approximate* $r^{1/4}$ law (typically over a factor of 30 in radius), suggesting that these systems will eventually become spirals with very massive central bulges or possibly even giant elliptical galaxies – the latter only if the remaining ISM is converted into stars at high efficiency. The majority of the sample galaxies, however, show no statistically significant preference for either an $r^{1/4}$ or exponential surface brightness profile over the range in radii probed by NICMOS.

We wish to acknowledge general contributions from many members of the NICMOS IDT which were critical to the success of these observations. C. Boone helped with an extensive literature search during the planning of these observations and G. Neugebauer, T. Soifer, J. Goldader, K. Matthews, N. Trentham, and J. Carpenter provided helpful discussions. Sylvain Veilleux providing very helpful suggestions as referee. We also thank R. Brunner and S. Odewahn for help with Source Extractor. The NICMOS project has been supported by NASA grant NAG 5-3042 to the NICMOS instrument definition team. This paper is based on observations with the NASA/ESA Hubble Space Telescope obtained at the Space Telescope Science Institute, which is operated by Association of Universities for Research in Astronomy, Incorperated, under NASA contract NAS5-26555.

APPENDIX

ADAPTIVE FILTERING

To show both the small scale structure of bright sources and at the same time bring out the extended low-surface brightness emission in the galaxy envelopes, we developed a variable resolution convolution routine (in IDL) which smooths the image with a boxcar filter with the resolution of the boxcar depending on the local signal-to-noise ratio in the image. The noise is measured near the sides of each image and the filter width at each pixel was set to $\gamma \times\ S(x,y)/\sigma$ where S(x,y) and σ are the flux at each pixel and the rms noise. The gain constant, γ, was set to $\sim$ 60 (based on trial runs). (Since the width could become very large where the signal was very weak, the maximum filter width was limited to the 10% of image width.) For contour images involving one wavelength, the local filter width followed the above prescription using the flux in the individual image, but for images involving the combination of more than one band (eg. the ratio images or for calculating the reddening – see below), the filter functions were determined for each band separately and then the applied filter at each pixel was taken to be the lowest resolution determined on either image. This ensured that

the combined image involved data at the same resolution. In addition, for combined images, both were also smoothed by an $0.2''$ resolution (FWHM) Gaussian filter after having been passed through the adaptive filtering routine.

An illustration of the variable smoothing is shown in Figure 14. In the right panel, a contour map of the unsmoothed image is shown, while on the left is the same data with the variable smoothing applied. The contours levels are the identical for the two images and it can be clearly seen that the apative filtering managed to retain all the original detail where the signal was high but also brought out the low level signals much more clearly. It is noteworthy also the bright sources in the outer part of the galaxy (where the adjacent background is low) are also retained at the nearly the original resolution – that is the filter resolution adjusts quickly to compact bright sources. The adaptive filtering used here has the advantages of being both conceptually simple and yielding a predictable resolution. Similar approaches have been explored before, although primarily for processing x-ray data Lorenz et al. 1993; Slezak, Durret, & Gerbal 1994; Biviano et al. 1996; Surace et al. 1999).

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FIG. 1.— The sample galaxies are plotted as a function of L_{ir} at λ=8-1000 μm and the IRAS 25μm/60μm flux ratio. The classification of the optical emission line ratios are indicated by the different symbols. The vertical line at 25μm/60μm = 0.2 divides the sample into cold and warm mid-infrared spectral types.

FIG. 2.— Three color images are shown for each galaxy arranged in order of increasing luminosity. The maximum area with detectable emission is displayed. The blue (1.1μm), green (1.6 μm) and red (2.2 μm) were individually log-stretched to bring out the maximum structure and to enhance the observed color gradients.

FIG. 3.— Shaded contour plots are shown for the central region of each galaxy arranged in order of increasing luminosity. The 1.1 (upper left), 1.6 (upper right) and 2.2 (lower left) μm images are plotted with logarithmic shading and contours spaced by factors $2^{1/3}$. The labelled contour values are the same for all galaxies; the lowest level ('1') is at a surface brightnes of 10^{-5} Jy arcsec $^{-2}$ and every 5'th contours is thickened and labelled (i.e. 5: 2.510^{-5}, 10: 7.810^{-5}, 15: 2.510^{-4}, 20: 7.710^{-4}, 25: $2.4.110^{-3}$, 30: $7.6.310^{-3}$, 35: 2.410^{-2} , 40: 7.510^{-2}, 45: 0.23 and 50: 0.74 Jy arcsec $^{-2}$.The ratio of the 2.2 and 1.1 μm images (lower right) has contours spaced by a factor of $2^{1/3}$ starting from a value of 0.5. The arcsec displacements in RA and DEC, given along the borders are measured from the 2.2 μm in all frames. At the upper left, a length bar is drawn. For the galaxies with strong point-sources, the PSF was fit to the source and then subtracted and replaced by a Gaussian with the proper integrated flux (see text – NGC 7469, IRAS 08572+3915, IRAS 05189-2524, PKS 1345+12, IRAS 07598+6508, Mrk 1014 and 3C48). As described in the text, the image data has been smoothed with an adaptive smoothing algorithm to reduce the noise (and spatial resolution) in lower brightness areas but retain the full resolution where the brightness is high (see Appendix). For the ratio image, both the 2.2 and 1.1 μm images were smoothed with the same adaptive smoothing and then smoothed with a Gaussian FWHM = 0.2″. In cases where a strong point-source or variable background contaminated the 2.2 μm image, the ratio was based on the 1.6 and 1.1 μm images.

FIG. 4.— Shaded contour plots of the extinction corrected 2.2 μm emission are shown together with the 1.1 μm (upper left) observed emission. In both panels, the contours and shading are logarithmic with the contours spaced by factors $2^{1/2}$. (The level values are the same as for Fig. 3). The arcsec displacements in RA and DEC, given along the borders are measured from the 2.2 μm in all frames. At the upper left, a length bar is drawn. For the ratio image, both the 2.2 and 1.1 μm images were smoothed with the same adaptive smoothing and then smoothed with a Gaussian FWHM = 0.2″ in calculating the 2.2 μm opacity from Eq. 3 (see text). In cases where a strong point-source or variable background contaminated the 2.2 μm image, the extinction corrected image was derived for 1.6 μm. For the galaxies with strong point-sources, the PSF was fit to the source and then subtracted and replaced by a Gaussian with the proper integrated flux (see text – NGC 7469, IRAS 08572+3915, IRAS 05189-2524, PKS 1345+12, IRAS 07598+6508, Mrk 1014 and 3C48).

FIG. 5.— $m_{1.1-1.6}$ and $m_{1.6-2.2}$ color-color diagram for the sample of galaxies with the fluxes measured in a 1.1″ diameter aperture with the adjacent background galaxy subtracted (i.e., 'nuclear' fluxes). The different symbols denote the luminosity and warm/cold galaxy classification. The locus for the evolution of an instantaneous starburst with Salpeter IMF is also show. The typical colors of free-free emission and optical PG QSOs are shown, the latter is plotted with variable percentages of 2.2 μm emission due to warm dust (see text). Lastly, the reddening vector based on the extinction curve of Rieke & Lebofsky (1985) is shown for two cases : a foreground screen of dust (the straight vector) and a model in which the dust is uniformly mixed with the emitting sources (the curved track). The models were redshifted to z= 0.05, corresponding to a typical redshift of the galaxies observed here.

FIG. 6.— Color-color diagram similar to Fig. 5 except the symbols denote the optical emission-line classification of the galaxies. Data for LIGs are plotted as unfilled symbols, and the data for ULIGs are plotted as filled symbols.

FIG. 7.— Color-color diagram similar to Fig. 5 except a fixed 2 kpc-diameter aperture was used. In the cases where the sources were too distant to use a 2 kpc-diameter aperture (i.e., PKS 1345+12, IR 07598+6508, Mrk 1014, 3C 48), a 1.1″-diameter aperture measurement was used.

FIG. 8.— Color-color diagram similar to Fig. 5 for the cluster sources with $SNR \geq 5$.

FIG. 9.— Mean surface brightness (Jy $''^{-2}$) as a function of projected radius in arcsec (top scale) and kpc (bottom scale) from the 2.2 μm peak in each galaxy. The 1.1, 1.6 and 2.2 μm surface brightnesses are plotted with solid, dashed and dotted lines respectively. Only in VV114, is the surface brightness plotted separately for the two galaxies; in some of the other objects, the secondary galaxy contribution can be seen as a peak at large offsets (eg. IRAS 14348-1447). The vertical bar on the top border indicates an angular radius of 0.12″(the radius of the diffraction resolution at 2.2 μm).

FIG. 10.— Mean surface brightness (Jy $''^{-2}$) as a function of projected $R^{1/4}$ in kpc from the 2.2 μm peak in each galaxy. The 1.1, 1.6 and 2.2 μm surface brightnesses are plotted with dotted, dashed and solid lines respectively. The vertical bar on the top border indicates an angular radius of 0.12″(the radius of the diffraction resolution at 2.2 μm).

FIG. 11.— The percentage of the integrated flux at projected radius 3 kpc is shown as a function of R (in Kpc). The 1.1, 1.6 and 2.2 μm growth curves are plotted with dotted, dashed, and solid lines respectively. The warm(W) or cold(C) classification of the mid-infrared emission of the galaxy is noted in the upper left and the vertical bar on the top border indicates an angular radius of 0.12″(the radius of the diffraction resolution at 2.2 μm).

FIG. 12.— The radius containing 50% of the total flux inside 3 kpc is plotted as a function of L_{ir} for galaxies with warm (W) and cold (C) mid-infrared color classification. The upper panel shows the half-light radius for the 1.1 μm emission and the lower panel that for the 2.2 μm emission.

FIG. 13.— The ratios of half-light radii at 1.6 to 1.1 μm (upper panel) and 2.2 to 1.1 μm (lower panel) are shown as a function of L_{ir} for galaxies with warm (W) and cold (C) mid-infrared color classification. The two warm objects with large R(2.2)/R(1.1) are simply unresolved.

FIG. 14.— Example of the use of the variable smoothing algorithm as applied to the 1.1 and 2.2 μm images for IRAS 17208-0014. In the upper panels are contours drawn from the original images and on the bottom contours drawn after the adaptive smoothing was applied. The contours a logarithmic, spaced by factors $2^{1/2}$ and are the same for all four panels. No attempt was made to remove PSF effects and the color fringes around such sources are due to the increasing width of the PSF at longer wavelengths (see text).

Table 1
Luminous IR Galaxies Observed w/ NICMOS

Name	Nuclear Spec.	IR Class.	z	log L_{ir}	log M(H_2)	NIR Morphology
NGC 4418	... [1]	W	.007	11.0	9.00	Nuclear dust disk
Zw049.057	H II[a]	C	.0131	11.22	8.78	Inclined dusty disk
NGC 6090	H II[a]	C	.0294	11.51	10.15	Double Galaxy, clusters and Pt. Nuc.
NGC 2623	... [1]	C	.0185	11.54	9.77	Spiral w/ clusters
IC 883	LINER[a]	C	.0231	11.60	9.87	Disk w/ dusty spiral
NGC 7469	Seyfert 1[a]	W	.0166	11.60	9.96	Pt. nucleus w/ spiral
VV 114	H II[a]	C	.0201	11.62	10.44	Double galaxies
NGC 6240	LINER[a]	C	.0243	11.82	10.29	Double nuclei (1.6″)
VIIZw031	H II[b]	C	.0542	11.94	10.69	Asymmetric Spiral
IRAS 15250+3609	LINER[a]	C	.0534	12.00	...	Double nuclei(?) (0.7″) + clusters
UGC 5101	LINER[a]	C	.0400	12.01	10.44	Pt. nucleus with disk
IRAS 10565+2448	H II[a]	C	.0430	12.02	10.34	Double galaxies (8″) w/ tail
IRAS 08572+3915	LINER[a]	W	.0582	12.09	9.79	Double galaxies (5″) w/ tail
IRAS 05189-2524	QSO[a,2,3]	W	.0427	12.10	10.37	Pt. nucleus
IRAS 22491-1808	H II[a]	C	.0773	12.10	10.43	Double nuclei (1.6″) + tails
Mrk 273	Seyfert 2[c]	C	.0378	12.11	10.24	Pt. double nuclei (1″)
Arp 220	LINER[c]	C	.0185	12.19	10.00	Double nuclei (1″) w/ dust
PKS 1345+12	Seyfert 2[c,2]	W	.1224	12.22	10.78	Double nuclei (3″)
IRAS 12112+0305	LINER[c]	C	.0727	12.26	10.62	Double nuclei (3″) w/ tail
IRAS 14348-1447	LINER[a]	C	.0825	12.27	10.78	Double Nuclei (3.5″)
IRAS 17208-0014	H II[a]	C	.0429	12.40	10.71	Nuclear disk w/ clusters
IRAS 07598+6508	Seyfert 1[c,4]	W	.149	12.45	10.73	Pt. nucleus + extended structure
Mrk 1014	QSO[d]	W	.163	12.49	10.61	QSO + spiral disk
3C 48	QSR[d]	W	.398	12.50	10.55	QSO with extended structure

References.—Emission line classifications: (a) Veilleux, Kim & Sanders (1999); (b) Djorgovski et al. (1990); (c) Kim, Veilleux, & Sanders (1998); (d) Schmidt & Green (1983).

[1] Reliable optical emission-line classifications of these two galaxies do not exist.

[2] Veilleux, Sanders & Kim (1999) have detected broad Paα emission from these galaxies, indicating that it contains a buried quasar nucleus.

[3] Young et al. (1996) have detected a QSO-like broad-line region in scattered light.

[4] Hines & Wills (1995) classify this as a BALQSO.

Table 2
Journal of Observations

Name	Date	Integration Time (sec) 1.1 μm	1.6 μm	2.2 μm
NGC 4418	1997 Nov 26	352	352	480
Zw049.057	1997 Dec 29	160	224	256
NGC 6090	1997 Nov 10	384	384	544
NGC 2623	1997 Nov 19	352	352	480
IC 883	1997 Nov 21	352	352	480
NGC 7469[a]	1997 Nov 10	352	352	480
VV 114E	1998 Aug 03	224	224	280
VV 114W	1998 Aug 03	224	224	280
NGC 6240[a]	1998 Feb 12	160	192	224
VII Zw 31	1997 Nov 17	600	600	680
IRAS 15250+3609[b]	1997 Nov 19	224	224	320
UGC 5101	1997 Nov 07	560	560	680
IRAS 10565+2448	1997 Nov 29	480	480	600
IRAS 08572+3915[b]	1997 Nov 11	224	160	288
IRAS 05189-2524[b]	1997 Dec 09	224	224	288
IRAS 22491-1808	1997 Nov 21	480	480	600
Mrk 273[b]	1997 Dec 10	256	256	320
Arp 220[b]	1997 Apr 04	1024	1024	1024
PKS 1345+12	1997 Dec 05	480	480	600
IRAS 12112+0305[b]	1997 Nov 15	192	192	224
IRAS 14348-1447	1997 Dec 31	480	480	600
IRAS 17208-0014[b]	1997 Oct 26	224	224	288
IRAS 07598+6508	1997 Nov 11	224	224	256
Mrk 1014	1997 Dec 13	480	480	600
3C 48	1997 Dec 11	480	480	600

[a] 2.2 μm Observations of a PSF star obtained during this orbit.

[b] 1.1, 1.6, and 2.2 μm observations of a PSF star obtained during this orbit.

Table 3
Morphological Features in IR Luminous Galaxies

Name	Nuclear Pt. Source[a]			Nuclear Separation		Clusters	Spiral[b]	Nuclear Dust[c]
	1.1	1.6	2.2μm	$''$	kpc			
NGC 4418							?	Y
Zw049.057						Y	Y	Y
NGC 6090	Y	Y	Y	6.0$''$	3.4	Y	Y	
NGC 2623						Y	Y	
IC 883						Y		Y
NGC 7469	Y	Y	Y	80$''$	26	Y	Y	
VV 114				14$''$	4.7	Y	Y	
NGC 6240				1.6$''$	0.8	Y		Y
VIIZw031						Y	Y	
IRAS 15250+36				(0.7$''$	0.7)	Y		
UGC 5101			Y			Y	Y	
IRAS 10565+2448				8.0$''$	6.7	Y	Y	
IRAS 08572+3915	Y	Y	Y	5.0$''$	5.6	Y		
IRAS 05189-2524	Y	Y	Y					
IRAS 22491-1808				1.6$''$	2.4	Y		Y
Mrk 273			Y	1.0$''$	0.7	Y		Y
Arp 220				0.9$''$	0.4	Y		Y
PKS 1345+12	Y	Y	Y	3.0$''$	7.1			Y
IRAS 12112+0305			Y	3.0$''$	4.2			Y
IRAS 14348-1447				3.5$''$	5.6	Y	Y	
IRAS 17208-0014						Y		
IRAS 07598+6508	Y	Y	Y					
Mrk 1014	Y	Y	Y				Y	
3C 48	Y	Y	Y					

[a]Point source at resolutions 0.1 – 0.2 $''$at 1.1 – 2.2 μm

[b]Spiral Arms seen in central 100 pc to 1 kpc.

[c]Strongly variable reddenning in nucleus.

Table 4
Aperture Photometry

Name	Aperture (Diameter)	$m_{1.1}$	$m_{1.6}$	$m_{2.2}$	$m_{1.1}$ - $m_{1.6}$	$m_{1.6}$ - $m_{2.2}$
NGC 4418	1.1″	14.98	13.85	13.26	1.13	0.59
	5.0″	13.22	12.21	11.77	1.00	0.44
	11.4″	12.54	11.62	11.25	0.91	0.36
Zw049.057	1.1″	16.02	14.72	13.98	1.30	0.74
	5.0″	13.88	12.69	12.16	1.19	0.54
	11.4″	10.25	9.33	8.48	0.92	0.85
NGC 6090E	1.1″	15.49	14.51	14.04	0.99	0.47
	5.0″	13.46	12.52	11.96	0.94	0.56
	11.4″	12.93	12.00	11.40	0.93	0.60
NGC 6090W	1.1″	16.45	15.62	15.19	0.83	0.43
	5.0″	14.59	13.79	13.42	0.80	0.38
NGC 2623	1.1″	15.10	13.29	12.10	1.81	1.19
	5.0″	13.52	12.16	11.37	1.36	0.79
	11.4″	12.80	11.58	11.08	1.22	0.49
IC 883	1.1″	16.08	14.32	13.11	1.76	1.21
	5.0″	13.92	12.58	11.69	1.34	0.88
	11.4″	13.16	12.00	11.24	1.16	0.76
NGC 7469	1.1″	12.41	11.14	9.89	1.27	1.25
	5.0″	11.43	10.23	9.23	1.20	1.00
	11.4″	11.14	9.96	9.05	1.18	0.92
VV 114E	1.1″	16.06	14.34	12.62	1.72	1.72
	5.0″	13.63	12.22	11.25	1.41	0.97
	11.4″	12.87	11.63	10.80	1.24	0.83
VV 114W	1.1″	15.63	14.85	14.52	0.78	0.33
	5.0″	13.46	12.65	12.30	0.81	0.32
	11.4″	12.66	11.82	11.47	0.84	0.35
NGC 6240S	1.1″	13.75	12.25	11.36	1.50	0.89
	5.0″	12.61	11.18	10.34	1.42	0.84
	11.4″	12.11	10.72	9.92	1.39	0.80
NGC 6240N	1.1″	14.83	13.45	12.72	1.38	0.74
	5.0″	12.62	11.19	10.36	1.42	0.83
	11.4″	12.10	10.71	9.91	1.39	0.80
VIIZw031	1.1″	15.33	14.05	13.29	1.28	0.75
	5.0″	13.65	12.43	11.68	1.21	0.76
	11.4″	13.21	12.06	11.22	1.15	0.83
IRAS 15250+3609	1.1″	16.18	14.90	14.06	1.27	0.84
	5.0″	14.63	13.58	12.99	1.05	0.59
	11.4″	14.46	13.41	12.77	1.06	0.64
UGC 5101	1.1″	14.92	13.32	11.77	1.61	1.55
	5.0″	13.66	12.25	11.09	1.41	1.16
	11.4″	13.22	11.88	10.84	1.34	1.04
IRAS 10565+2448	1.1″	14.84	13.42	12.49	1.42	0.93
	5.0″	13.64	12.38	11.60	1.26	0.79
	11.4″	13.38	12.18	11.46	1.20	0.72
IRAS 08572+3915N	1.1″	17.45	15.80	13.53	1.65	2.27
	5.0″	16.21	14.80	13.20	1.42	1.59
	11.4″	15.85	14.20	13.06	1.64	1.15
IRAS 08572+3915S	1.1″	16.87	15.86	15.76	1.01	0.11
	5.0″	16.68	15.64	15.74	1.04	-0.09
IRAS 22491-1808W	1.1″	16.61	15.62	15.08	0.99	0.54
	5.0″	15.09	14.06	13.59	1.04	0.46
	11.4″	14.67	13.71	13.70	0.96	0.01
IRAS 22491-1808E	1.1″	17.34	16.11	15.37	1.23	0.74
IRAS 05189-2524	1.1″	13.56	11.83	10.33	1.73	1.50
	5.0″	13.06	11.48	10.08	1.58	1.40

Table 4—*Continued*

Name	Aperture (Diameter)	$m_{1.1}$	$m_{1.6}$	$m_{2.2}$	$m_{1.1}$ - $m_{1.6}$	$m_{1.6}$ - $m_{2.2}$
	11.4″	13.02	11.40	10.02	1.61	1.38
Mrk 273S	1.1″	16.04	14.52	13.29	1.52	1.22
	5.0″	13.60	12.36	11.55	1.24	0.80
	11.4″	12.94	11.79	11.15	1.14	0.64
Mrk 273N	1.1″	15.36	13.93	12.91	1.44	1.02
	5.0″	13.56	12.33	11.53	1.23	0.80
Arp 220W	1.1″	15.93	14.00	12.79	1.93	1.21
	5.0″	13.76	12.21	11.22	1.55	0.99
	11.4″	12.84	11.54	10.74	1.30	0.80
Arp 220E	1.1″	16.50	14.49	13.13	2.01	1.36
PKS 1345+12W	1.1″	16.66	15.45	13.96	1.20	1.49
	5.0″	15.10	14.00	13.02	1.10	0.98
	11.4″	14.42	13.34	12.42	1.07	0.92
PKS 1345+12E	1.1″	16.86	15.85	15.31	1.01	0.54
IRAS 12112+0305S	1.1″	16.88	15.37	14.37	1.51	1.00
	5.0″	15.74	14.42	13.72	1.32	0.70
	11.4″	14.86	13.58	12.96	1.28	0.62
IRAS12112+0305N	1.1″	15.81	14.62	13.89	1.19	0.72
IRAS 14348-1447S	1.1″	16.58	15.09	14.19	1.49	0.90
	5.0″	15.23	14.02	13.35	1.22	0.66
	11.4″	14.63	13.45	12.91	1.18	0.54
IRAS 14348-1447N	1.1″	17.24	15.71	14.92	1.53	0.79
	5.0″	15.70	14.36	13.86	1.35	0.50
IRAS 17208-0014	1.1″	16.15	14.33	13.12	1.82	1.21
	5.0″	14.02	12.58	11.74	1.44	0.83
	11.4″	13.38	12.09	11.49	1.30	0.60
IRAS 07598+6508	1.1″	13.40	12.02	10.51	1.38	1.51
	5.0″	13.24	11.82	10.34	1.42	1.48
	11.4″	13.23	11.78	10.34	1.45	1.44
Mrk 1014	1.1″	14.80	13.56	12.25	1.24	1.31
	5.0″	14.41	13.16	11.98	1.25	1.18
	11.4″	14.37	13.04	11.97	1.34	1.075
3C 48	1.1″	14.87	14.00	12.82	0.87	1.18
	5.0″	14.71	13.76	12.64	0.95	1.12
	11.4″	14.73	13.74	12.65	0.99	1.08

Table 5
Nuclear Photometry[a]

Name	$m_{1.1}$	$m_{1.6}$	$m_{2.2}$	$m_{1.1}$ - $m_{1.6}$	$m_{1.6}$ - $m_{2.2}$
NGC 4418*	16.04	14.78	14.05	1.26	0.73
Zw049.057*	17.18	15.98	15.20	1.20	0.78
NGC 6090E*	16.37	15.40	14.94	0.97	0.45
NGC 6090W*	17.26	16.40	15.94	0.85	0.47
NGC 2623*	15.69	13.65	12.34	2.04	1.31
IC 883*	17.20	15.02	13.66	2.18	1.36
NGC 7469	12.41	11.14	9.89	1.27	1.25
NGC 6240S*	14.03	12.53	11.66	1.50	0.86
NGC 6240N*	15.60	14.31	13.69	1.28	0.62
VIIZw031*	16.07	14.80	14.08	1.28	0.71
IRAS 15250+3609*	16.94	15.39	14.38	1.55	1.01
UGC 5101*	15.44	13.79	12.04	1.64	1.75
IRAS 10565+2448*	15.62	14.05	13.02	1.57	1.04
IRAS 08572+3915N	17.45	15.80	13.53	1.65	2.27
IRAS 08572+3915S	16.87	15.86	15.76	1.01	0.11
IRAS 22491-1808W*	16.92	15.94	15.37	0.98	0.57
IRAS 22491-1808E*	18.55	17.13	16.16	1.42	0.97
IRAS 05189-2524	13.56	11.83	10.33	1.73	1.50
Mrk 273S*	17.29	15.29	13.77	2.01	1.51
Mrk 273N*	16.04	14.23	13.25	1.81	0.98
Arp 220W*	17.13	14.88	13.48	2.25	1.40
Arp 220E*	17.86	15.94	14.43	1.92	1.51
PKS 1345+12W*	17.06	15.85	14.14	1.21	1.71
PKS 1345+12E*	17.39	16.41	15.91	0.98	0.50
IRAS 12112+0305S*	17.19	15.60	14.51	1.58	1.09
IRAS 14348-1447S*	17.05	15.36	14.49	1.69	0.87
IRAS 14348-1447N*	18.02	16.00	15.31	2.03	0.69
IRAS 17208-0014*	17.20	15.30	13.85	1.90	1.44
IRAS 07598+6508	13.40	12.02	10.51	1.38	1.51
Mrk 1014	14.80	13.56	12.25	1.24	1.31
3C 48	14.87	14.00	12.82	0.87	1.18

[a]Measured in a 1.1″ aperture.

*Underlying galaxy subtraction performed.

Table 6
2 Kpc-Diameter Aperture Photometry

Name	$m_{1.1}$	$m_{1.6}$	$m_{2.2}$	$m_{1.1}$ - $m_{1.6}$	$m_{1.6}$ - $m_{2.2}$
NGC 4418	12.33	11.46	11.14	0.87	0.32
Zw049.057	13.39	12.24	11.81	1.15	0.43
NGC 6090E	13.82	12.89	12.38	0.92	0.51
NGC 6090W	14.98	14.17	13.76	0.82	0.41
NGC 2623	13.40	12.06	11.34	1.33	0.73
IC 883	14.02	12.65	11.77	1.36	0.88
NGC 7469	11.34	10.14	9.17	1.20	0.97
VV114E	13.54	12.15	11.22	1.39	0.93
VV114W	13.39	12.57	12.24	0.82	0.33
NGC 6240N	12.85	11.39	10.56	1.46	0.84
NGC 6240S	12.71	11.28	10.46	1.43	0.82
VIIZw031	14.59	13.32	12.57	1.27	0.75
IR 15250+3609	15.41	14.28	13.59	1.13	0.69
UGC 5101	14.12	12.61	11.33	1.51	1.28
IR 10565+2448	14.02	12.69	11.86	1.33	0.83
IR 08572+3915N	16.92	15.42	13.42	1.50	2.00
IR 08572+3915S	17.44	16.45	15.60	0.99	0.85
IR 22491-1808W	16.42	15.42	14.92	0.99	0.50
IR 22491-1808E	16.91	15.72	15.05	1.19	0.67
IR 05189-2524	13.19	11.59	10.19	1.60	1.40
Mrk 273N	14.20	12.87	11.94	1.33	0.93
Mrk 273S	14.26	12.90	11.97	1.35	0.93
Arp 220	13.61	12.10	11.16	1.51	0.94
IR 12112-0305N	16.66	15.20	14.28	1.46	0.92
IR 12112-0305S	17.04	15.68	14.79	1.36	0.89
IR 14348-1447N	17.01	15.65	14.80	1.36	0.85
IR 14348-1447S	16.42	15.01	14.10	1.41	0.91
IR 17208-0014	14.82	13.20	12.21	1.62	0.98

Table 7
Cluster Photometry

Number	$m_{1.1}$	$\Delta m_{1.1}$[b]	$m_{1.6}$	$\Delta m_{1.6}$[b]	$m_{2.2}$	$\Delta m_{2.2}$[b]	$m_{1.1}$ - $m_{1.6}$	$m_{1.6}$ - $m_{2.2}$	N Offset[c] ($''$)	E Offset[c] ($''$)
					Zw049.057					
01	19.68	0.16	18.71	0.10	>18.55[a]	0.00	0.97	0.00	0.3	1.1
02	20.16	0.24	19.53	0.20	>16.52	0.00	0.63	0.00	0.4	0.9
					NGC 6090E					
01	18.26	0.02	18.15	0.03	18.20	0.15	0.11	-.05	-1.6	0.4
02	18.69	0.03	18.58	0.04	18.73	0.23	0.11	-.14	-1.2	-0.3
03	19.14	0.04	19.23	0.08	>19.09	0.00	-.09	0.00	-1.0	-0.7
04	19.19	0.05	18.83	0.05	18.59	0.21	0.36	0.24	-5.1	3.6
05	19.39	0.06	18.84	0.05	18.74	0.23	0.56	0.10	-5.1	3.3
06	19.46	0.06	18.34	0.03	17.47	0.08	1.13	0.87	-1.9	-2.0
07	19.64	0.07	18.90	0.06	19.01	0.29	0.73	-.11	-5.0	4.7
08	19.70	0.07	18.59	0.04	18.54	0.20	1.11	0.05	-1.0	-1.4
09	19.76	0.08	19.42	0.09	>19.09	0.00	0.33	0.00	-0.4	-1.0
10	19.88	0.09	19.46	0.10	>19.08	0.00	0.42	0.00	-5.4	3.8
11	19.91	0.09	19.18	0.07	18.88	0.26	0.73	0.30	-4.9	5.0
12	19.99	0.09	19.41	0.09	18.83	0.25	0.58	0.57	0.4	-0.8
13	20.13	0.11	19.19	0.07	>19.10	0.00	0.94	0.00	1.7	-0.1
14	20.19	0.11	19.47	0.10	>19.09	0.00	0.72	0.00	-5.2	3.2
15	20.32	0.13	19.56	0.10	>19.01	0.00	0.76	0.00	-1.2	-1.4
16	20.33	0.13	19.80	0.13	>19.10	0.00	0.53	0.00	-4.8	2.5
17	20.69	0.17	19.73	0.12	18.97	0.28	0.96	0.76	-2.1	1.2
18	20.71	0.18	19.83	0.13	>19.06	0.00	0.88	0.00	-2.1	0.8
19	20.84	0.20	>20.85	0.00	>19.08	0.00	0.00	0.00	-1.3	-1.1
20	20.92	0.21	20.36	0.21	>19.03	0.00	0.57	0.00	1.5	0.2
21	20.99	0.22	20.29	0.20	>19.09	0.00	0.70	0.00	0.5	1.7
22	>21.38	0.00	20.49	0.23	>19.09	0.00	0.00	0.00	-2.0	1.5
					NGC 2623					
01	19.50	0.07	18.84	0.06	18.84	0.25	0.66	0.00	-7.9	1.2
02	20.27	0.15	19.66	0.13	>19.10	0.00	0.61	0.00	-1.2	-2.4
03	20.84	0.24	19.47	0.11	>19.10	0.00	1.37	0.00	1.4	1.4
04	20.99	0.27	19.86	0.15	18.35	0.17	1.14	1.51	0.3	2.6
05	>21.15	0.00	20.28	0.21	18.37	0.17	0.00	1.91	-1.2	1.7
					IC 883					
01	18.02	0.02	17.56	0.02	17.62	0.10	0.45	-.06	4.8	7.7
02	18.31	0.03	16.34	0.01	15.41	0.01	1.97	0.93	-0.4	-0.7
03	18.34	0.03	17.27	0.02	16.88	0.05	1.07	0.39	1.2	1.7
04	19.07	0.06	18.75	0.07	18.57	0.22	0.32	0.18	-2.8	-0.2
05	19.09	0.06	18.50	0.05	18.17	0.16	0.59	0.33	2.0	-0.1
06	20.56	0.21	19.53	0.13	18.75	0.26	1.04	0.78	-0.5	-1.5
07	20.75	0.24	19.98	0.19	>18.98	0.00	0.77	0.00	1.3	-2.2
08	20.76	0.24	20.25	0.24	>18.95	0.00	0.50	0.00	7.2	-1.5
09	20.93	0.28	20.19	0.23	>18.95	0.00	0.74	0.00	1.4	-2.9
10	>21.06	0.00	19.16	0.09	18.09	0.15	0.00	1.07	1.7	2.3
11	>21.07	0.00	20.40	0.27	>18.95	0.00	0.00	0.00	0.8	1.6
12	>21.07	0.00	20.44	0.28	>18.92	0.00	0.00	0.00	-2.9	-2.1
					NGC 7469					
01	16.76	0.01	16.34	0.01	15.82	0.02	0.42	0.53	-1.6	0.6
02	17.41	0.01	16.93	0.01	16.74	0.04	0.48	0.20	1.0	-1.3
03	17.58	0.01	17.21	0.02	16.19	0.03	0.37	1.02	1.2	-1.1
04	17.91	0.02	18.17	0.04	17.54	0.09	-.26	0.62	1.7	0.0
05	18.79	0.03	18.64	0.05	19.03	0.29	0.15	-.38	9.3	-3.5
06	19.10	0.05	>20.30	0.00	18.60	0.23	0.00	0.00	-0.5	1.6
07	19.98	0.11	19.41	0.12	18.57	0.22	0.58	0.83	-2.6	-2.6
08	20.01	0.11	19.27	0.10	>18.98	0.00	0.74	0.00	-3.2	-1.7
09	20.87	0.24	20.06	0.21	>18.97	0.00	0.81	0.00	-9.2	-0.9
10	21.10	0.29	19.99	0.19	>18.96	0.00	1.11	0.00	-3.0	-2.0
					VV 114E					
01	18.30	0.04	18.09	0.06	18.14	0.22	0.21	-.05	-3.2	1.5
02	18.79	0.06	17.82	0.04	17.47	0.12	0.96	0.35	-4.1	2.0
03	18.87	0.06	16.31	0.01	15.31	0.02	2.56	1.00	1.3	-0.9
04	18.88	0.06	17.17	0.02	16.21	0.04	1.71	0.96	-0.5	0.7
05	19.00	0.07	17.63	0.04	16.66	0.06	1.37	0.97	1.7	-0.8
06	19.69	0.13	18.42	0.07	>18.54	0.00	1.27	0.00	1.0	-0.8
07	19.69	0.13	19.44	0.18	>18.54	0.00	0.25	0.00	2.5	-1.3
08	19.72	0.13	18.65	0.09	18.00	0.20	1.06	0.65	2.2	-1.2
09	19.78	0.14	19.37	0.17	>18.54	0.00	0.41	0.00	-0.7	1.5
10	19.83	0.14	19.17	0.14	>18.50	0.00	0.67	0.00	2.0	-1.0
11	20.03	0.17	18.89	0.11	18.20	0.23	1.13	0.69	1.8	-0.1
12	20.25	0.20	19.53	0.19	18.49	0.30	0.72	1.04	1.0	0.3
13	20.29	0.21	19.52	0.19	>18.54	0.00	0.77	0.00	0.4	1.3
14	20.45	0.24	19.02	0.12	>18.55	0.00	1.43	0.00	2.7	-1.7
15	20.67	0.29	19.89	0.26	>18.52	0.00	0.78	0.00	2.1	-2.4
16	20.75	0.31	>20.09	0.00	>18.36	0.00	0.00	0.00	-1.3	1.5
17	>20.75	0.00	19.73	0.23	>18.54	0.00	0.00	0.00	2.1	-1.8
18	>20.76	0.00	19.81	0.25	>18.53	0.00	0.00	0.00	3.0	-2.6
19	>20.76	0.00	20.03	0.29	>18.50	0.00	0.00	0.00	0.5	1.1
					VV 114W					
01	18.15	0.03	17.60	0.03	17.57	0.14	0.55	0.03	0.1	0.1
02	18.53	0.05	17.90	0.04	17.84	0.17	0.63	0.06	2.7	5.3
03	18.78	0.06	19.11	0.13	>18.53	0.00	-.33	0.00	-3.7	6.4
04	18.84	0.06	18.50	0.08	18.10	0.22	0.34	0.40	-0.9	-0.3
05	19.06	0.07	18.28	0.06	17.90	0.19	0.78	0.37	0.8	3.6

Table 7—*Continued*

Number	$m_{1.1}$	$\Delta m_{1.1}$[b]	$m_{1.6}$	$\Delta m_{1.6}$[b]	$m_{2.2}$	$\Delta m_{2.2}$[b]	$m_{1.1}$ - $m_{1.6}$	$m_{1.6}$ - $m_{2.2}$	N Offset[c] ($''$)	E Offset[c] ($''$)
06	19.09	0.08	19.38	0.16	18.53	0.31	-.29	0.85	2.2	5.7
07	19.39	0.10	19.16	0.14	>18.51	0.00	0.23	0.00	-0.2	-0.5
08	19.45	0.11	19.31	0.16	>18.52	0.00	0.15	0.00	1.9	-2.3
09	19.71	0.13	18.93	0.11	>18.53	0.00	0.78	0.00	1.6	-0.6
10	19.75	0.14	19.54	0.19	>18.51	0.00	0.21	0.00	3.3	4.8
11	19.92	0.16	19.80	0.24	>18.48	0.00	0.12	0.00	-3.7	2.8
12	19.92	0.16	19.90	0.26	>18.50	0.00	0.03	0.00	7.0	4.6
13	20.00	0.17	19.31	0.16	>18.51	0.00	0.69	0.00	2.3	5.4
14	20.11	0.19	19.49	0.18	>18.51	0.00	0.63	0.00	2.5	1.0
15	20.12	0.19	>20.14	0.00	>18.47	0.00	0.00	0.00	0.6	-0.1
16	20.16	0.20	19.76	0.23	>18.51	0.00	0.40	0.00	4.3	3.5
17	20.24	0.21	19.28	0.15	>18.52	0.00	0.96	0.00	2.2	2.3
18	20.50	0.26	19.85	0.25	>18.51	0.00	0.65	0.00	4.9	-0.5
19	20.52	0.26	19.80	0.24	>18.50	0.00	0.73	0.00	1.8	4.8
20	20.57	0.28	19.72	0.22	>18.50	0.00	0.85	0.00	3.7	2.4
21	20.58	0.28	>20.13	0.00	>18.49	0.00	0.00	0.00	-2.0	7.1
22	20.59	0.28	19.84	0.24	>18.52	0.00	0.75	0.00	2.2	4.7
23	20.59	0.28	20.13	0.31	>18.50	0.00	0.46	0.00	6.8	1.7
24	20.65	0.29	19.65	0.21	>18.50	0.00	1.00	0.00	1.6	1.8
25	20.69	0.30	>20.12	0.00	>18.50	0.00	0.00	0.00	3.9	0.9
26	>20.53	0.00	19.93	0.26	>18.39	0.00	0.00	0.00	2.9	4.9
27	>20.72	0.00	19.75	0.23	>18.51	0.00	0.00	0.00	2.0	2.3
NGC 6240S										
01	18.93	0.09	18.37	0.08	>18.44	0.00	0.57	0.00	-0.6	-6.5
02	19.21	0.11	18.61	0.10	>18.44	0.00	0.59	0.00	-3.0	6.4
VIIZw031										
01	19.20	0.04	18.09	0.02	17.51	0.08	1.11	0.58	-0.8	0.0
02	19.30	0.04	18.48	0.03	17.31	0.07	0.83	1.17	-0.1	-0.7
03	19.41	0.05	18.57	0.03	18.19	0.14	0.84	0.38	-0.9	-1.3
04	19.55	0.05	18.58	0.03	18.02	0.12	0.97	0.56	0.7	0.9
05	19.73	0.06	18.51	0.03	18.17	0.14	1.22	0.34	1.4	0.3
06	19.86	0.07	19.46	0.07	18.41	0.17	0.40	1.05	-0.9	-1.0
07	19.89	0.07	18.72	0.04	18.05	0.13	1.18	0.66	1.0	-0.4
08	19.95	0.07	18.21	0.02	17.86	0.11	1.74	0.34	0.5	0.1
09	19.98	0.07	19.50	0.07	>19.10	0.00	0.47	0.00	0.7	-0.7
10	20.06	0.08	19.30	0.06	18.90	0.26	0.77	0.40	-2.5	-1.8
11	20.18	0.09	19.18	0.06	18.52	0.19	1.00	0.66	-2.8	-1.8
12	20.20	0.09	18.91	0.04	18.42	0.18	1.30	0.48	-1.0	0.3
13	20.29	0.10	19.26	0.06	18.60	0.21	1.02	0.66	-0.8	1.3
14	20.31	0.10	19.21	0.06	18.61	0.21	1.10	0.61	-1.1	-0.6
15	20.41	0.11	18.76	0.04	17.78	0.10	1.65	0.97	1.3	0.0
16	20.47	0.12	18.89	0.04	18.20	0.15	1.58	0.69	-1.0	-0.3
17	20.64	0.13	19.17	0.05	>19.11	0.00	1.47	0.00	-0.3	0.5
18	20.68	0.14	19.29	0.06	18.70	0.22	1.39	0.59	-1.9	-0.1
19	20.71	0.14	19.91	0.10	>19.10	0.00	0.80	0.00	-0.7	0.8
20	20.88	0.17	19.68	0.09	>19.06	0.00	1.20	0.00	-0.7	0.6
21	21.39	0.26	20.11	0.13	>19.09	0.00	1.28	0.00	0.4	-1.3
22	21.45	0.27	19.71	0.09	18.45	0.18	1.73	1.27	-1.1	-0.2
23	21.45	0.27	20.92	0.25	>18.95	0.00	0.53	0.00	-0.5	3.2
24	21.59	0.30	19.43	0.07	18.97	0.28	2.16	0.47	-0.3	0.8
25	21.60	0.30	20.07	0.12	>19.10	0.00	1.53	0.00	-1.0	-0.8
26	21.62	0.31	20.60	0.19	>18.85	0.00	1.03	0.00	0.5	-2.8
27	>21.63	0.00	21.07	0.28	>19.05	0.00	0.00	0.00	-0.6	-3.1
28	>21.63	0.07	19.97	0.11	>19.11	0.00	0.00	0.00	0.4	-0.6
IR 15250+3609										
01	18.49	0.04	17.81	0.04	17.92	0.16	0.67	-.11	0.5	0.4
02	19.70	0.11	18.99	0.10	>18.71	0.00	0.71	0.00	-0.3	0.4
03	20.37	0.19	19.85	0.22	>18.68	0.00	0.53	0.00	2.0	-1.0
04	20.61	0.24	>20.29	0.00	>18.68	0.00	0.00	0.00	0.8	0.8
UGC 5101										
01	19.60	0.05	18.74	0.04	>18.57	0.00	0.86	0.00	-0.7	-0.4
02	20.52	0.12	19.70	0.09	>19.21	0.00	0.82	0.00	3.4	-0.8
03	>21.66	0.00	20.25	0.15	>19.20	0.00	0.00	0.00	1.6	-2.0
IR 10565+2448W										
01	18.42	0.02	17.98	0.02	17.41	0.06	0.45	0.56	0.4	-0.3
02	19.01	0.03	18.71	0.04	17.31	0.06	0.30	1.40	-1.1	0.3
03	21.15	0.22	20.51	0.21	>19.20	0.00	0.64	0.00	-0.4	-4.1
IR 22491−1808W										
01	19.36	0.05	18.44	0.03	18.19	0.13	0.92	0.26	1.7	-0.5
02	19.87	0.08	19.15	0.06	18.74	0.21	0.72	0.41	-0.7	-0.6
03	20.49	0.14	19.90	0.12	>19.21	0.00	0.60	0.00	2.4	1.9
04	21.01	0.21	19.80	0.11	>19.22	0.00	1.21	0.00	-1.3	-1.1
05	21.20	0.25	20.41	0.19	>19.20	0.00	0.79	0.00	2.0	1.3
06	>21.47	0.00	20.33	0.18	>19.20	0.00	0.00	0.00	1.4	0.1
Mrk 273S										
01	19.49	0.10	19.89	0.22	18.13	0.21	-.40	1.76	1.0	-0.2
Arp 220W										
01	18.99	0.03	17.61	0.02	17.16	0.05	1.38	0.45	0.2	0.7
02	20.30	0.09	19.42	0.08	19.29	0.30	0.89	0.13	-1.5	4.8
03	21.25	0.20	20.67	0.25	>19.30	0.00	0.58	0.00	4.7	2.3
04	21.59	0.27	>20.95	0.00	>19.30	0.00	0.00	0.00	-0.7	2.3
05	21.61	0.28	>20.95	0.00	>19.15	0.00	0.00	0.00	-5.2	-4.5
IR 17208-0014										

TABLE 7—*Continued*

Number	$m_{1.1}$	$\Delta m_{1.1}$[b]	$m_{1.6}$	$\Delta m_{1.6}$[b]	$m_{2.2}$	$\Delta m_{2.2}$[b]	$m_{1.1}$ - $m_{1.6}$	$m_{1.6}$ - $m_{2.2}$	N Offset[c] ($''$)	E Offset[c] ($''$)
01	19.24	0.07	17.76	0.03	16.96	0.07	1.48	0.80	0.3	0.7
02	19.44	0.08	18.63	0.07	17.91	0.15	0.80	0.72	0.9	-0.6
03	19.48	0.09	18.43	0.06	17.90	0.15	1.05	0.53	1.2	-1.0
04	19.57	0.09	18.81	0.08	>18.74	0.00	0.76	0.00	0.2	-1.2
05	19.66	0.10	19.20	0.12	>18.76	0.00	0.46	0.00	1.0	-0.2
06	19.94	0.13	19.28	0.12	>18.76	0.00	0.66	0.00	0.7	-0.7
07	20.01	0.14	19.24	0.12	>18.77	0.00	0.78	0.00	1.1	-1.2
08	20.13	0.15	19.32	0.13	18.60	0.27	0.81	0.73	0.9	-1.5
09	20.22	0.17	17.86	0.03	16.56	0.05	2.36	1.30	0.4	0.2
10	20.25	0.17	19.63	0.17	>18.78	0.00	0.62	0.00	-0.7	-0.8
11	20.62	0.24	20.04	0.24	>18.76	0.00	0.59	0.00	-0.1	-0.7
12	20.65	0.24	>20.29	0.00	>18.77	0.00	0.00	0.00	-0.7	-0.6
13	20.82	0.28	20.08	0.25	>18.74	0.00	0.73	0.00	2.4	-2.5
14	20.86	0.29	20.26	0.28	>18.75	0.00	0.61	0.00	-1.3	-0.6
15	>20.95	0.00	19.06	0.10	18.29	0.21	0.00	0.77	-0.6	-0.3
16	>20.95	0.00	19.36	0.13	>18.75	0.00	0.00	0.00	0.8	0.7
17	>20.96	0.00	19.84	0.20	>18.78	0.00	0.00	0.00	8.5	-5.0
18	>20.96	0.00	20.11	0.25	>18.76	0.00	0.00	0.00	-1.3	-0.3

[a]Upper limits on all magnitudes are 3σ rms upper limits.

[b]1 Sigma root-mean-square for the corresponding measured magnitude.

[c]Offset in arcseconds from the brightest 2.2μm peak.

Table 8
Radial Profile Fits

Galaxy	R_{inner} [a] (pc)	R_{outer} [a] (pc)	Best Model[b] ($r^{1/4}$ or exp)	Scale[c] (kpc)	χ^2 [d]	Ratio [e] χ^2s
NGC 4418	30	1100	$\mathbf{r^{1/4}}$	0.710	0.84	26
Zw049.057	60	2000	$\mathbf{r^{1/4}}$	2.180	0.38	7
NGC 6090	120	3000	exp	0.690	2.19	2
NGC 2623	90	2900	$\mathbf{r^{1/4}}$	1.480	1.38	6
IC 883	100	3800	$\mathbf{r^{1/4}}$	2.180	0.26	11
NGC 7469	70	3100	neither			
VV114E	90	2300	**exp**	0.520	0.94	3
VV114W	80	1700	exp	0.560	0.87	1
NGC 6240	95	4500	$\mathbf{r^{1/4}}$	1.340	0.27	19
VIIZw031	230	7000	neither			
IRAS 15250+3609	250	5150	$r^{1/4}$	1.730	2.26	2
UGC 5101	180	6180	$\mathbf{r^{1/4}}$	1.420	0.34	19
IRAS 10565+2448	250	6300	$\mathbf{r^{1/4}}$	1.150	1.03	23
IRAS 08572+3915	260	2200	neither			
IRAS 05189–2524	170	5800	neither			
IRAS 22491–1808	300	7000	$r^{1/4}$	8.290	1.67	2
Mrk 273	170	5100	exp	1.060	1.25	1
Arp 220	90	3400	$\mathbf{r^{1/4}}$	2.800	0.50	7
PKS 1345+12	480	6900	neither			
IRAS 12112+0305	310	2000	$r^{1/4}$	1.190	4.53	3
IRAS 14348–1447	360	3000	$\mathbf{r^{1/4}}$	4.190	0.84	8
IRAS 17208–0014	180	6600	$r^{1/4}$	2.610	2.72	2
IRAS 07598+6508	680	6900	neither			
Mrk 1014	700	6900	exp	1.980	6.22	2

[a]In all cases, the inner radius for the fit, R_{inner}, is at 0.22″ radius to be outside the difraction radius. Usually, R_{outer}, the outer radius for the fit is at the detection edge of the galaxy, but in a few instances, R_{outer} was reduced to avoid a secondary nucleus.

[b]Functional form of best fitting model to the 1.6 μm image. Entries with bold type are those with excellent fits and where the fit clearly discriminates the $r^{1/4}$-law and exponential forms.

[c]Scale length for best-fit function. For $r^{1/4}$, this is the radius in which half the total flux is contained; for the exponential disk, it is the e-folding length in radius.

[d]χ^2 normalized by the number of radial bins in the fit.

[e]The ratio of χ^2's for the worse fitting model to the better fitting model. This serves as an estimator of how well the data favors the best-fit model over the other model, i.e. a ratio of 1 means both fits are equally acceptable and a high ratio implies that the best-fit funtion is highly favored.

Table 9
Half-Light Radii For Flux within 3 kpc

Name	IR Class	$R_{1/2}(1.1\mu m)$ kpc	$R_{1/2}(1.6\mu m)$ kpc	$R_{1/2}(2.2\mu m)$ kpc
NGC 4418	W	0.34	0.32	0.26
Zw049.057	C	0.68	0.62	0.44
NGC 6090	W	1.06	1.12	1.07
NGC 2623	C	0.92	0.73	0.39
IC 883	C	1.05	0.93	0.62
NGC 7469	W	0.21	0.27	0.27
VV 114E	C	0.87	0.79	0.61
VV 114W	C	0.86	0.87	0.78
NGC 6240	C	0.79	0.73	0.61
VIIZw031	C	1.35	1.28	1.17
IRAS 15250+36	C	1.09	1.01	0.65
UGC 5101	C	1.01	0.80	0.45
IRAS 10565+24	C	0.89	0.79	0.65
IRAS 08572+39	W	0.83	0.69	0.14
IRAS 05189-25	W	0.14	0.10	0.12
IRAS 22491-18	C	1.60	1.66	1.62
Mrk 273	C	1.31	1.17	0.90
Arp 220	C	1.33	1.09	0.58
PKS 1345+12	W	1.03	1.08	0.39
IRAS 12112+0305	C	0.97	0.79	0.45
IRAS 14348-1447	C	1.23	1.07	0.67
IRAS 17208-0014	C	1.28	1.10	0.88
IRAS 07598+65	W	0.17	0.22	0.30
Mrk 1014	W	0.24	0.28	0.36

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